SCHOOL OF CIVIL ENGINEERING

INDIANA DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

JHRP-89/5 — 1

Final Report

AN INVESTIGATION OF SURFACE COATINGS ON EXPOSED CONCRETE

Luh M. Chang

Peter S. Garner

PURDUE UNIVERSITY

JOINT HIGHWAY RESEARCH PROJECT

JHRP-89/5 — 1

Final Report

AN INVESTIGATION OF SURFACE COATINGS ON EXPOSED CONCRETE

Luh M. Chang

Peter S. Garner

AN INVESTIGATION OF SURFACE COATINGS ON EXPOSED CONCRETE

by

Luh M. Chang, JHRP Research Engineer, Purdue University

Peter S. Garner, Graduate Research Assistant

Joint Highway Research Project

Project No.: C-36-67BB

File No.: 9-11-28

PURDUE UNIVERSITY

School of Civil Engineering

West Lafayette, Indiana

May 1989

ACKNOWLEDGMENTS

The authors wish to acknowledge with gratitude the assistance and support of the many individuals who helped to make this project possible.

Very special thanks are extended to Richard Smutzer, Don Scott, Tony Zander, and the many other people of the Indiana Department of Highways Division of Materials and Testing. Without their effort, assistance, dedication, and use of their facilities, this project would have been severely limited.

TABLE OF CONTENTS

Page

APPENDICES

LIST OF TABLES

Page

Page

LIST OF FIGURES

Page

ABSTRACT

Garner, Peter Scott. M.S., Purdue University, May 1989. An Investigation of Surface Coatings on Exposed Concrete. Major Professor: Luh M. Chang.

The deterioration of concrete structures is accelerated when damaging chemical substances are allowed to penetrate the concrete and cause corrosion of the reinforcing steel. In recent years, attempts to eliminate this problem have been made through the application of surface coatings/sealers to the concrete. However, the current practice of coating seems a somewhat complicated process requiring sandblasting prior to sealing, followed by another sandblasting in preparation for coating. In addition, the advent of these surface treatments has not been accompanied by a simple means of assessing their performance in terms of both permeability and resistance to weathering.

The objective of this study, which was funded by the Indiana Department of Highways, was to evaluate generic types of sealer/coating systems and ascertain which are suitable for use on non-wearing concrete surfaces in the State of Indiana. This was accomplished by studying the effectiveness of different surface sealers/ coatings when applied on concrete and subjected to different

laboratory experiments. The effectiveness was established by determining if these materials could minimize or prevent the intrusion of chloride-concentrated water into the concrete while maintaining structural and esthetic integrity.

The results of this project show that a wide variety of generic types of chemicals are being used to seal concrete structures. However, the performance of these numerous materials in minimizing the absorption of saltwater into concrete was found to be highly variable. Many of the chemicals were quite ineffective in reducing the water and chloride absorption characteristics during simple saltwater soaking tests. The same was true for the rapid chloride permeability testing. There was also observed a large performance variation within a given generic type of chemical, such as within the epoxies, the urethanes, the silanes, etc.

Although significant variations in performance exist, there are certain chemical formulations of materials that exhibit excellent performance. The specific chemical formulations and performance records for these materials are identified in the report. Two test procedures are suggested for use by chemical manufacturers, highway agencies, and testing laboratories to evaluate the performance of sealers/coatings.

Even though certain sealer materials can significantly reduce the intrusion of chloride into concrete, the use of properly consolidated and cured low water/cement ratio concrete, and adequate cover over the embedded reinforcing steel is still needed for long-term protection in severe environments.

CHAPTER 1
INTRODUCTION AND RESEARCH OBJECTIVES

Introduction

The deterioration of concrete structures is accelerated when damaging chemical substances like salt, acids, water, are allowed to penetrate the concrete and cause corrosion of the reinforcing steel. Expansion during the corrosion process causes stresses which eventually lead to cracking of the concrete mass. The cracking in turn facilitates the permeation of destructive chemicals. If allowed to continue unchecked, the structural integrity of the member eventually becomes jeopardized (1).

Throughout the world, corrosion of the reinforcing steel is primarily caused by the intrusion of chloride ions into the concrete. The concrete is exposed to these ions as a result of the use of deicing chemicals during the winter. In recent years, attempts to eliminate this problem have been made through the application of surface sealers/coatings to the concrete. The use of effective surface sealers, coatings, or penetrants on bridge members or other concrete structures would prevent permeation of the chloride ions. This in turn could extend the life of the bridge structures, reduce maintenance and rehabilitation costs, and enhance the appearance of the structure.

The use of sealers/coatings for the prevention of chloride ion permeation has met with varying degrees of success. In addition, it is not uncommon for the use of sealers/coatings to result in uneven discoloration of the concrete surface thereby degrading the esthetics of the structure.

The current practice of coating seems a somewhat complicated process requiring sandblasting prior to sealing, followed by another sandblasting in preparation for coating. Another practice involves a two step procedure requiring wet rubbing of the concrete with a carborundum stone. Since both of these practices are time and labor intensive, the identification of an effective one step procedure could lead to substantial labor savings.

In addition, the advent of these surface treatments has not been accompanied by a simple means of assessing their performance in terms of both permeability and resistance to weathering.

Research Objective

The objective of this research is to evaluate generic types of sealer/coating systems and ascertain which are suitable for use in highway construction on non-wearing concrete surfaces within the State of Indiana. This was accomplished by studying the effectiveness of different surface sealers/coatings when applied on concrete and subjected to different laboratory experiments. The effectiveness was established by determining if these materials could minimize or prevent the intrusion of chloride-concentrated

water into the concrete while maintaining structural and esthetic integrity.

Research Approach

Since this research was aimed at investigating as many different chemical types of sealers/coatings as possible, the research approach included an extensive literature search of libraries, interviews with personnel of surrounding highway departments, and contacting chemical companies to select the appropriate generic types of coating systems for testing. Three different laboratory experiments were undertaken on the selected materials. Thus, the research consisted of the following tasks:

Task 1 - Identify the present state of the art of sealers/coating that are available on the market and that are used successfully in the surrounding states by means of an extensive literature search.

Task 2 - Determine the ability of these sealers/coatings to resist water and chloride ion absorption and vapor transmission.

Task 3 - Examine the ability of these sealers/coatings to resist chloride ion penetration in a chloride ion permeability test.

Task 4 - Determine the resistance of these sealers/coatings to accelerated weathering in terms of ultra-violet radiation, heat, and freeze/thaw cycles.

Task 5 - Recommend proper procedures for application of these sealers/coatings and means of laboratory evaluation.

CHAPTER 2
FINDINGS

Literature Search

In 1979, a similar study (National Cooperative Highway Research Program - Report No. 244) was undertaken to evaluate the effectiveness of the sealers/coatings that were on the market at that time. Since then, new products have been introduced and this project was aimed at investigating these new materials as well as many of the older ones using the same testing methods that were used in the 1979 Report No. 244.

A literature search was completed in the Potter Engineering library at Purdue University using Thomas' Register and Sweets Manual. Also reviewed was information and literature received from the Indiana, Ohio, Tennessee, Illinios, Kentucky, Texas, and Florida state departments of transportation. This search revealed the concrete sealer/coatings presently being utilized by the above states. A questionnaire regarding the technical data of concrete sealers was sent to 119 chemical companies. Product information received from 54 out of 119 suppliers of coatings that answered the questionnaire was analyzed. From the 54 chemical companies that responded, 42 companies suggested 120 different materials.

Review of the information and literature received from the departments of transportation of Indiana and the surrounding states indicated that epoxy is one of the most widely used sealant materials. The solids content was generally in the range of 15 to 100 percent. They have been tested by many departments of transportation and independent laboratories and are being used by many states. Two coats are usually recommended to insure sufficient protection. The opinions of the surrounding state departments of transportation are consistent in that they feel very confident about using epoxy as a sealer.

Many of these departments of transportation have been testing and evaluating an alkyl-alkoxy silane penetrant. This silane material, unlike other coatings, blocks the porosity of concrete, forms a hydrophobic layer that repels liquid water but allows vapor permeation or breathing. Many of these state DOTs also feel that this material is an excellent concrete sealer. Siloxane is another sealer that is very similar to the silane material and is beginning to be used more extensively by many states with great success. One coat is recommended for the silane and siloxane materials.

A few of the other generic types that are being used by the surrounding states are as follows: methyl methacrylate, elastomer/polyester, acrylic polymer, polyester resin, and vinyl acrylic latex. All of the above materials are being thoroughly tested both in the field and the laboratory by many state departments of transportation and independent laboratories.

Many of the chemical companies submitted data on the following tests: chloride-ion penetration, freeze/thaw, accelerated weathering, salt resistance, etc.... These tests were done by NCHRP Report No. 244, state departments of transportation, and independent testing laboratories. This data weighed heavily in determining the samples that would be selected for further testing. From the submitted information and data, 25 coatings or penetrants were selected from different chemical companies which generally include all of the generic types of materials most widely used today. The selected materials for evaluation in this project were as follows:

	Test No.
Epoxies:	
Five epoxies with varying percent solids	1,2,4,25,26
One epoxy containing polysulfide	3
Penetrants:	
Four alkyl-alkoxy silanes	7,8,9,10
Silicone	11
Siloxane	14
A siloxane/silicone combination	15
Poly-siloxane/hydrophobic-fumed silica	21
Combination of many forms of silane	18
Masonry Coatings:	
Styrene Acrylic copolymer	16,22
Vinyl acrylic latex	19
Polyester resin	20
Elastomeric acrylic	23

Acrylic resin	24
Other:	
Two types of urethane	5,6
Two materials based on methacrylate	12,13

These materials could be classified into four general groups. The first group included all of the epoxies. This particular group contained epoxies with varying degrees of percent solids, ranging from 20 to 100 percent. All of the epoxies were classified as penetrating epoxies with the exception of No. 25 which was a 100 percent solids content epoxy. The second group included the remaining penetrants. This group contained all four of the silanes, a silicone, a siloxane, the siloxane/silicone mixture, the poly-siloxane/hydrophobic-fumed silica, and the combination of many forms of silanes. The third group included all seven of the masonry coatings. The last group contained both urethanes and both methyl methacrylates.

Chloride Ion Permeability Test

The objective of the chloride ion permeability test was to determine the ability of the sealers/coatings in resisting chloride intrusion when applied on concrete. Another objective of this phase of the testing was to ascertain at what stage during the curing period applying the epoxy penetrants is most effective. The cylinders were made from the same mix design, but not the same batch.

The chloride ion permeability results of the five penetrating epoxies that were applied at age 7 days, 14 days, and 28 days are shown in Table 1. According to AASHTO T 277-83I (2), the four epoxies with the 50 percent solids content had very low ratings when they were applied at the age of 14 and 28 days. However, all four of these epoxies had low ratings when they were applied on the concrete at the age of seven days. The 20 percent solids epoxy was fairly consistent with a low rating in each of the three different testing periods. The permeability of concrete should decrease as it becomes more hydrated and this was shown with the increased percent chloride reductions with increased curing times from seven to 28 days.

The chloride ion permeability results for all 25 materials (coated at age 28 days) are shown in Table 2. Two materials reduced the chloride intrusion by over 90 percent compared to the control and one of them, the 100 percent solids epoxy, had a negligible permeability rating. The other material, a chemically-cured urethane with 55 percent solids content, had a very low rating. Six of the materials exhibited very low permeability values ranging from 80 to 90 percent of that of the uncoated concrete. Eleven materials demonstrated low permeability values between 58 and 80 percent compared to the control specimen. The last six materials exhibited moderate permeability values ranging from 35 to 54 percent of that of the untreated concrete.

Five out of the top seven materials were epoxy formulations. The best material was the 100 percent solids epoxy and the other

Table 1

Rapid Chloride Permeability Results - AASHTO T 277-83I
Penetrating Epoxies

Coated at 7 Days

Sample Number	Generic Type (% solids)	Coulombs Passed	Percent Reduction	AASHTO Designation
3	Epoxy (50)	1061	52.9	low
4	Epoxy (50)	1396	39.2	low
26	Epoxy (50)	1689	25.0	low
1	Epoxy (50)	1718	23.7	low
2	Epoxy (20)	1914	15.0	low
*CONTROL	-----	2251	----	moderate

Coated at 14 Days

Sample Number	Generic Type (% solids)	Coulombs Passed	Percent Reduction	AASHTO Designation
4	Epoxy (50)	226	90.9	very low
3	Epoxy (50)	527	78.8	very low
1	Epoxy (50)	607	75.6	very low
26	Epoxy (50)	978	60.7	very low
2	Epoxy (20)	1437	42.3	low
*CONTROL	-----	2491	----	moderate

Coated at 28 Days

Sample Number	Generic Type (% solids)	Coulombs Passed	Percent Reduction	AASHTO Designation
3	Epoxy (50)	467	90.0	very low
26	Epoxy (50)	509	89.1	very low
4	Epoxy (50)	546	88.3	very low
1	Epoxy (50)	661	85.8	very low
2	Epoxy (20)	1829	60.7	low
*CONTROL	-----	**4657	----	high

* Two control specimens were tested and their values averaged for each test.
** The permeability of control should have decreased with increasing curing time.
Testing at IDOH has produced results from 1230 to 3075 coulombs on the control specimens. Refer to reference No. 6.

Table 2

Rapid Chloride Permeability Results - AASHTO T 277-831

28 Days Air Drying

Sample Number	Generic Type (% solids)	Coulombs Passed	Percent Reduction	AASHTO Designation
25	Epoxy (100)	66	98.58	negligible
5	Urethane (55)	258	94.46	very low
3	Epoxy (50)	467	89.97	very low
26	Epoxy (50)	509	89.07	very low
10	Silane (40)	538	88.45	very low
4	Epoxy (50)	546	88.28	very low
1	Epoxy (50)	661	85.81	very low
7	Silane (40)	792	82.99	very low
13	Methyl Methacrylate (30)	997	78.59	very low
8	Silane (<20)	1002	78.48	low
12	Methyl Methacrylate (20)	1117	76.01	low
14	Siloxane (20)	1226	73.67	low
11	Silicone (5)	1369	70.60	low
15	Siloxane/Silicone (10)	1623	65.15	low
19	Vinyl Acrylic (58)	1788	61.61	low
9	Silane (20)	1812	61.09	low
2	Epoxy (20)	1829	60.73	low
20	Polyester Resin (60)	1853	60.21	low
16	Styrene Acrylic Cop. (61)	1939	58.36	low
24	Acrylic Resin	2170	53.40	moderate
23	Elastomeric Acrylic	2255	51.58	moderate
18	Blend of Silanes (30)	2421	48.01	moderate
22	Styrene Acrylic Cop. (75)	2470	46.96	moderate
21	Poly-siloxane/silica (7)	2680	42.45	moderate
6	Urethane (30)	3006	35.45	moderate
*CONTROL	-----	**4657	-----	high

* Two control specimens were tested and their values averaged for this test.
** The permeability of control should have decreased with increasing curing time.
*** Testing at IDOH has produced results from 1230 to 3075 coulombs on the control specimens. Refer to reference No. 6.

four materials were the 50 percent solids epoxies. The next best generic type was the silane. The silanes with the higher solids contents were much more effective than the ones with 20 percent or less solids. Both methyl methacrylates were around 77 percent more effective than the uncoated control specimen. Siloxane, silicone, and the combination of the two had permeability values between 65 and 74 percent of that of the untreated concrete. The rest of the materials, all six of the masonry coatings, a blend of silanes, a polysiloxane/silica, and a moisture-cured urethane, had permeability values below 62 percent of that of the control specimen.

Accelerated Weathering

The objective of this test was to determine the influence of 24 weeks (6 months) of accelerated laboratory weathering tests on the performance of the selected sealers/coatings when applied to small concrete slabs. The northern climate test (3) method used an accelerated weathering cycle in which the coated slabs were exposed to a wide range of environmental conditions which included ultraviolet light, high heat, acid/saltwater, fresh water rinse, freezing, and thawing.

The performance of the sealers/coatings was judged by making periodical visual inspections of the surface conditions (this included photographs), by measuring the gloss of the surface with a glossmeter every two weeks, and by measuring the chloride ion content in the concrete at the end of the testing period.

All specimens exhibited some degree of surface deterioration or discoloration, except for the chemically-cured urethane and four of the masonry coatings. The epoxy formulations exhibited varying degrees of discoloration and deterioration from the effects of this testing. The 100 percent solids epoxy discolored some but did not deteriorate. The 20 solids epoxy demonstrated the worst deterioration of all the epoxies. The performance of the epoxy seems to be directly related to the amount of solids present in the epoxy. There was only a slight deterioration of the surface of the slabs coated with the penetrants (silane, siloxane, silicone, and combinations of three). Only one silane (<20 percent solids), the combination of siloxane and silicone, and the blend of silanes exhibited significant surface deterioration. The moisture-cured urethane, straight methyl methacrylate, and one of the styrene acrylic copolymers (75 percent solids) also had deep etching over their entire surfaces. The other styrene acrylic copolymer (61 percent solids) exhibited minor surface deterioration and the methyl methacrylate with the silane primer had some slight discoloration of the surface coating. The untreated control specimen exhibited uniform deep etching over the entire surface and had many coarse aggregate showing.

Table 3 shows the glossmeter values at the week 0 and week 24 of the accelerated weathering test. All of the tested materials exhibited a decrease in their gloss with the exception of the slabs coated sealed with silane. The coatings that experienced any deterioration or discoloration also had a subsequent loss of gloss.

Table 3

Glossmeter - Initial and Final Readings

Sample Number	Generic Type (% solids)	Initial Week 0	Final Week 24	Percent Reduction
1	Epoxy (50)	5.95	0.78	86.89
2	Epoxy (20)	0.75	0.02	97.33
3	Epoxy (50)	1.55	0.08	94.84
4	Epoxy (50)	9.53	0.48	94.96
5	Urethane (55)	3.93	1.85	52.93
6	Urethane (30)	1.90	0.10	94.74
7	Silane (40)	0.23	0.08	65.22
8	Silane (<20)	0.25	0.00	100.00
9	Silane (20)	0.13	0.13	0.00
10	Silane (40)	0.23	0.23	0.00
11	Silicone (5)	0.15	0.03	80.00
12	Methyl Methacrylate (20)	4.15	1.50	63.86
13	Methyl Methacrylate (30)	1.88	0.28	85.11
14	Siloxane (20)	0.73	0.10	86.30
15	Siloxane/Silicone (10)	0.53	0.00	100.00
16	Styrene/Acrylic Coploymer (75)	0.58	0.00	100.00
18	Blend of Silanes (30)	0.25	0.05	80.00
19	Vinyl Acrylic (58)	1.35	1.15	14.81
20	Polyester Resin (60)	0.30	0.03	90.00
21	Poly-siloxane/Silica (7)	0.55	0.00	100.00
22	Styrene/Acrylic Coploymer (61)	1.55	1.05	32.26
23	Elastomeric Acrylic	1.20	0.93	22.50
24	Acyrlic Resin	0.88	0.70	20.45
25	Epoxy (100)	14.20	0.73	94.86
Control	----	0.20	0.00	-----

The epoxy formulations all experienced large decreases in their glossmeter values. The masonry coatings that were still fully intact at the end of the testing period showed only slight drops in their gloss.

The chloride content values for the 24 tested materials and the control specimen are given in Table 4. The data provided in Table 4 was the raw chloride titration values given to us by the Indiana Department of Highways. The chloride content of the untreated control specimen was very high at the end of the test, 0.423 percent by weight of concrete. There were two samples that actually exhibited higher chloride contents than the control. They were the two masonry coatings that were based on the styrene acrylic copolymer (16 and 22). There were five materials that reduced the chloride content by over 90 percent of that of the untreated control (three silanes - 10, 8, and 7; a siloxane; and the blend of silanes). Six materials were between 80 and 90 percent more effective than the control specimen (a silicone; a silane - 9; three epoxies - 1, 3, and 25; and the siloxane/silica mixture). Two of the 24 tested materials were between 50 and 80 percent more effective than the control (an epoxy - 4, and a urethane - 5). There were, however, eight materials that were less than twice as effective as the untreated control (four masonry coatings - 19, 20, 23, and 24; an epoxy - 2; a urethane - 6; and both methyl methacrylates - 12 and 13).

Table 4

Average Percent Chlorides - Ponding Slabs

Sample Number	Generic Type (% solids)	Average % Chloride	Percent Reduction
1	Epoxy (50%)	0.0750	82.26
2	Epoxy (20%)	0.4075	3.64
3	Epoxy (50%)	0.0554	86.91
4	Epoxy (50%)	0.1245	70.56
5	Urethane (55%)	0.1363	67.78
6	Urethane (30%)	0.2953	30.18
7	Silane (40%)	0.0376	91.11
8	Silane (<20%)	0.0349	91.75
9	Silane (20%)	0.0496	88.26
10	Silane (40%)	0.0295	93.02
11	Silicone (5%)	0.0444	89.51
12	Methyl Methacrylate (20%)	0.2306	45.46
13	Methyl Methacrylate (30%)	0.4099	3.08
14	Siloxane (20%)	0.0415	90.19
15	Siloxane/Silicone (10%)	0.2940	30.48
16	Styrene/Acrylic Copolymer (75%)	0.4822	-14.03
18	Blend of Silanes (30%)	0.0319	92.46
19	Vinyl Acrylic (58%)	0.2861	32.34
20	Polyester Resin (60%)	0.2894	31.57
21	Poly-Siloxane/Silica (7%)	0.0814	80.76
22	Styrene/Acrylic Copolymer (61%)	0.5280	-24.86
23	Elastomeric Acrylic	0.2923	30.89
24	Acyrlic Resin	0.3480	17.71
25	Epoxy (100%)	0.0449	89.39
CONTROL	-----	0.4229	-----

Water Absorption, Vapor Transmission, & Chloride Titration

The objectives of this phase of the project were to evaluate the differences in water and chloride ion absorption for concrete coated with the 24 materials soaked in a 15 percent NaCl saltwater solution. The subsequent water vapor transmission characteristics were also compared during an air drying period which followed the soaking period. Another objective of this phase was to examine the differences achieved from allowing the concrete to cure to different stages before applying the selected materials (Set 1 - 9 days, Set 2 - 19 days, and Set 3 - 28 days).

The discussion of the results from this phase of the testing are divided by the individual sets.

Set 1

The water absorption characteristics for all of the tested materials for Set 1 are given in Table 5. Three of the materials exhibited very low water absorption values over 90 percent of that of the uncoated concrete (two epoxies - 1 and 4 and a methyl methacrylate - 12). 13 materials reduced the chloride content between 70 and 90 percent compared to the control (three epoxies - 2, 3, and 25; all four silanes; a silicone - 11; a methyl methacrylate - 13; a urethane - 5; a siloxane - 14; a siloxane/silicone mixture - 15; and a masonry coating - 20). Three of the materials were between 50 and 70 percent more effective than the control specimen (two

Table 5

Chloride Contents & Weight Change Results - Set 1

Test Number	Generic Type (% solids)	CHLORIDE CONTENT % by Weight	Percent Reduction	WEIGHT GAIN % by Weight	Percent Reduction	Residual Wt. Change % by wt.	Weight Loss, % by weight	Weight Loss Weight Gain Ratio, %
1	Epoxy (50)	0.0597	77.97	0.19	92.75	-0.60	0.79	420.0
2	Epoxy (20)	0.1113	58.49	0.57	78.24	-1.06	1.63	286.7
3	Epoxy (50)	0.1518	43.99	0.49	81.30	-0.94	1.43	292.0
4	Epoxy (50)	0.0723	73.32	0.15	94.27	-0.65	0.80	525.0
5	Urethane (55)	0.0658	75.72	0.56	78.63	-0.30	0.86	153.3
6	Urethane (30)	0.2138	21.11	1.77	32.44	-0.45	2.22	125.3
7	Silane (40)	0.1045	61.44	0.68	74.05	-1.05	1.73	255.6
8	Silane (<20)	0.0617	77.23	0.53	79.77	-1.07	1.60	300.0
9	Silane (20)	0.0937	65.42	0.76	70.99	-0.99	1.75	230.0
10	Silane (40)	0.0997	62.73	0.42	83.97	-1.10	1.52	363.6
11	Silicone (5)	0.0540	80.07	0.53	79.77	-1.05	1.58	300.0
12	Methyl Methacrylate (20)	0.0437	83.87	0.15	94.27	-1.36	1.51	1000.0
13	Methyl Methacrylate (30)	0.0907	66.53	0.72	72.52	-0.87	1.59	221.1
14	Siloxane (20)	0.0985	63.65	0.38	85.80	-1.21	1.59	470.0
15	Siloxane/Silicone (10)	0.0930	65.68	0.72	72.52	-0.95	1.67	231.6
16	Styrene/Acrylic Co. (75)	0.0920	66.05	0.97	62.98	-0.76	1.73	176.9
18	Blend of Silanes (30)	0.1952	27.97	1.21	53.82	-0.78	1.99	162.5
19	Vinyl Acrylic (58)	0.2568	5.24	1.84	29.77	-0.18	2.02	110.0
20	Polyester Resin (60)	0.1003	62.73	0.63	75.95	-0.92	1.55	247.1
21	Poly-Siloxane/Silica (7)	0.2810	-3.69	2.12	19.08	-0.38	2.50	117.9
22	Styrene/Acrylic Co. (61)	0.1015	62.55	0.90	65.65	-0.67	1.57	175.0
23	Elastomeric Acrylic	0.2213	18.34	1.50	42.75	-0.26	1.76	114.0
24	Acrylic Resin	0.2837	-4.69	1.87	28.63	-0.22	2.09	111.8
25	Epoxy (100)	0.0367	86.46	0.36	86.26	0.07	0.29	80.0
Control	-----	0.2710	0.00	2.62	0.00	0.00	2.62	0.0

masonry coatings - 16 and 22, a blend of silanes - 18). There were five materials that were under twice as effective as the untreated control (three masonry coatings - 19, 23, and 24; a moisture-cured urethane - 6; and a poly-siloxane/silica - 21).

Table 5 also shows the chloride absorption characteristics as well as the ratios of weight loss to weight gain for all of the 24 materials. Only three materials had over an 80 percent reduction in chloride content compared to the untreated control (an epoxy - 25, a methyl methacrylate - 12, and a silicone - 11). Material No. 12 also lost 10 times the weight that it gained. The silicone was lost three times the weight that it gained. Four materials reduced the chloride content between 70 and 80 percent of that of the untreated control (two epoxies - 1 and 4, a urethane - 5, and a silane - 8). Material Nos. 1 and 4 had weight loss to weight gain ratios of 4.2 and 5.3, respectively. Ten materials exhibited chloride content reductions ranging from 50 to 70 percent of that of the untreated control (two epoxies - 2 and 3; three silanes - 7, 9, and 10; a siloxane - 14; a siloxane/silicone mixture - 15; and three masonry coatings - 16, 20, and 22). Two of these materials, the siloxane - 14 and a silane - 10, had fairly high weight loss to weight gain ratios at 4.7 and 3.6, respectively, but were only around 63 percent more effective against water absorption than the control.

Set 2

The water absorption characteristics of the tested materials for Set 2 are displayed in Table 6. Three of the tested materials demonstrated very low water absorption values of over 90 percent of that of the untreated control (two epoxies - 4 and 12, and a methyl methacrylate - 12). There were nine materials that exhibited water absorption characteristics between 70 and 90 percent of that of the control (an epoxy - 1; a urethane - 5; three silanes - 7, 8, and 10; a silicone - 11; a siloxane - 14, a siloxane/silicone mixture - 15; and a blend of silanes - 18). Six materials had water absorption values ranging from 50 to 70 percent of that of the untreated control (two epoxies - 2 and 3; a silane - 9; and three masonry coatings - 16, 20 and 22). The six remaining materials were less than twice as effective as the control (a methyl methacrylate - 13; a urethane - 6; a poly-siloxane/silica - 21; and three masonry coatings - 19, 23, and 24).

Table 6 also shows the chloride absorption characteristics as well as the ratios of weight loss to weight gain for all of the 24 materials. Seven materials exhibited over an 80 percent reduction of chlorides compared to the untreated control (two epoxies - 4 and 25, a urethane - 5, two silanes - 7 and 8, a silicone - 11, and a methyl methacrylate - 12). Material Nos. 25 and 5 both had very low weight loss to weight gain ratios at 0.8 and 1.0, respectively. On the other hand, No. 12's ratio was 6.8, No. 4's ratio was 4.7, No. 11's ratio was 4.4, and No. 8's ratio was 3.2. Only two materials had chloride content

Table 6

Chloride Contents & Weight Change Results - Set 2

Test Number	Generic Type (% solids)	CHLORIDE CONTENT % by Weight	CHLORIDE CONTENT Percent Reduction	WEIGHT GAIN % by Weight	WEIGHT GAIN Percent Reduction	Residual Wt. Change % by wt.	Weight Loss % by wt.	Weight Loss Weight Gain Ratio, %
1	Epoxy (50)	0.0522	76.00	0.34	86.45	-0.34	0.68	180.0
2	Epoxy (20)	0.0760	65.06	0.76	69.72	-0.80	1.56	205.0
3	Epoxy (50)	0.1157	46.80	1.06	57.77	-0.38	1.44	135.7
4	Epoxy (50)	0.0370	82.99	0.11	95.62	-0.41	0.52	466.7
5	Urethane (55)	0.0275	87.36	0.36	85.66	0.00	0.36	100.0
6	Urethane (30)	0.1730	20.46	1.94	22.71	-0.30	2.24	115.7
7	Silane (40)	0.0418	80.78	0.60	76.10	-0.79	1.39	231.3
8	Silane (<20)	0.0428	80.32	0.45	82.07	-0.98	1.43	316.7
9	Silane (20)	0.1225	43.68	0.76	69.72	-0.80	1.56	205.0
10	Silane (40)	0.0570	73.79	0.34	86.45	-0.92	1.26	366.7
11	Silicone (5)	0.0388	82.16	0.34	86.45	-1.18	1.52	444.4
12	Methyl Methacrylate (20)	0.0380	82.53	0.19	92.43	-1.09	1.28	680.0
13	Methyl Methacrylate (30)	0.1318	39.40	1.34	46.61	-0.54	1.58	140.0
14	Siloxane (20)	0.0847	61.06	0.36	85.66	-1.07	1.43	380.0
15	Siloxane/Silicone (10)	0.1068	50.90	0.68	72.91	-0.87	1.55	227.8
16	Styrene/Acrylic Co. (75)	0.0725	66.67	1.00	60.16	-0.66	1.66	166.7
18	Blend of Silanes (30)	0.0747	65.66	0.49	80.48	-0.91	1.40	284.6
19	Vinyl Acrylic (58)	0.2037	63.34	1.65	34.26	-0.15	1.80	108.9
20	Polyester Resin (60)	0.0948	56.41	0.93	62.95	-0.74	1.67	180.0
21	Poly-Siloxane/Silica (7)	0.2405	-10.57	2.16	13.94	-0.30	2.46	114.0
22	Styrene/Acrylic Co. (61)	0.0992	54.39	1.15	54.18	-0.59	1.74	151.6
23	Elastomeric Acrylic	0.1603	26.30	1.83	27.09	-0.04	1.87	102.0
24	Acrylic Resin	0.2232	-2.62	1.96	21.91	-0.04	2.00	101.9
25	Epoxy (100)	0.0268	87.68	0.22	91.24	0.04	0.18	83.3
Control	-----	0.2175	0.00	2.51	0.00	-0.23	2.74	109.1

The water absorption characteristics of the 24 tested materials in Set 3 are displayed in Table 7. Only one material, a methyl methacrylate - 12, had a very low water absorption value over 90 percent more effective than the control. 12 materials exhibited low

Table 7 also shows the chloride absorption characteristics as well as the ratios of weight loss to weight gain for all of the 24 materials. Seven materials exhibited over an 80 percent reduction of chlorides compared to the control (two silanes - 8 and 10, a silicone - 11, a methyl methacrylate - 12, a siloxane - 14, a siloxane/silicone mixture - 15, and a masonry coating - 16). Material No. 12 lost over seven times the weight that it gained. Material Nos. 8, 10, 11, and 14 all lost over four times the weight that they gained. Five materials were between 70 and 80 percent more effective against chloride intrusion than that of the control (three epoxies - 1, 2, and 25; a methyl methacrylate - 13; and a blend of silanes - 18). Material Nos. 2 and 18 both lost over three times the weight that they gained. Five materials had average chloride content reduction values ranging from 50 to 70 percent of that of the untreated control (an epoxy - 4, a urethane - 5, a silane - 7, and two masonry coatings - 20 and 22). One of the silanes, No. 7 also lost over four times what it gained but was only around 61 percent more effective against chloride intrusion.

Table 7

Chloride Contents & Weight Change Results - Set 3

Test	Generic	CHLORIDE CONTENT		WEIGHT GAIN		Residual	Weight	Weight Loss
Number	Type (% solids)	% by Weight	Percent Reduction	% by Weight	Percent Reduction	Wt. Change % by wt.	Loss % by wt.	Weight Gain Ratio, %
1	Epoxy (50)	0.0598	77.28	0.42	80.91	-0.53	0.95	227.3
2	Epoxy (20)	0.0545	79.29	0.42	80.91	-1.03	1.45	345.5
3	Epoxy (50)	0.1943	34.27	0.94	57.27	-0.45	1.39	148.0
4	Epoxy (50)	0.0797	69.72	0.49	77.73	-0.34	0.83	169.2
5	Urethane (55)	0.0967	63.26	0.79	64.09	-0.08	0.87	104.8
6	Urethane (30)	0.3070	-16.64	2.05	6.82	0.00	2.05	100.0
7	Silane (40)	0.1005	61.82	0.38	82.73	-1.22	1.60	420.0
8	Silane (<20)	0.0392	85.11	0.30	86.36	-1.10	1.40	462.5
9	Silane (20)	0.1567	40.46	0.53	75.91	-1.03	1.56	292.9
10	Silane (40)	0.0488	81.46	0.27	87.73	-1.02	1.29	485.7
11	Silicone (5)	0.0453	82.79	0.34	84.55	-1.21	1.55	455.6
12	Methyl Methacrylate (20)	0.0328	87.54	0.19	91.36	-1.21	1.40	740.0
13	Methyl Methacrylate (30)	0.0698	73.48	0.87	60.45	-0.76	1.63	187.0
14	Siloxane (20)	0.0385	85.37	0.34	84.55	-1.18	1.52	444.4
15	Siloxane/Silicone (10)	0.0402	84.73	0.49	77.73	-1.13	1.62	330.8
16	Styrene/Acrylic Co. (75)	0.0495	81.19	0.95	56.82	-0.70	1.65	173.1
18	Blend of Silanes (30)	0.0618	76.52	0.49	77.73	-0.99	1.48	300.0
19	Vinyl Acrylic (58)	0.1602	39.13	1.71	22.27	-0.36	2.07	121.3
20	Polyester Resin (60)	0.0965	63.34	1.34	39.09	-0.77	2.11	167.7
21	Poly-Siloxane/Silica (7)	0.2020	23.25	1.99	9.55	-0.41	2.40	120.8
22	Styrene/Acrylic Co. (61)	0.1127	57.18	1.34	39.09	-0.63	1.97	147.2
23	Elastomeric Acrylic	0.2183	17.06	1.91	13.18	-0.08	1.99	103.8
24	Acrylic Resin	0.1973	25.04	1.67	24.09	-0.36	2.03	121.7
25	Epoxy (100)	0.0665	74.73	0.29	86.82	0.15	0.14	50.0
Control	-----	0.2632	0.00	2.20	0.00	-0.34	2.54	115.5

Table 7 also shows the chloride absorption characteristics as well as the ratios of weight loss to weight gain for all of the 24 materials. Seven materials exhibited over an 80 percent reduction of chlorides compared to the control (two silanes - 8 and 10, a silicone - 11, a methyl methacrylate - 12, a siloxane - 14, a siloxane/silicone mixture - 15, and a masonry coating - 16). Material No. 12 lost over seven times the weight that it gained. Material Nos. 8, 10, 11, and 14 all lost over four times the weight that they gained. Five materials were between 70 and 80 percent more effective against chloride intrusion than that of the control (three epoxies - 1, 2, and 25; a methyl methacrylate - 13; and a blend of silanes - 18). Material Nos. 2 and 18 both lost over three times the weight that they gained. Five materials had average chloride content reduction values ranging from 50 to 70 percent of that of the untreated control (an epoxy - 4, a urethane - 5, a silane - 7, and two masonry coatings - 20 and 22). One of the silanes, No. 7 also lost over four times what it gained but was only around 61 percent more effective against chloride intrusion.

CHAPTER 3
INTERPRETATION AND SUGGESTED TEST METHODS

Interpretation

The results of this project indicated that a wide variety of generic types of chemicals are being used to seal or coat the concrete structures of highways. However, the performance of these numerous types of generic materials in minimizing the intrusion of salt waters and resisting deterioration and discoloration from accelerated weathering was quite variable. Many of the chemical materials demonstrated relatively good characteristics in one test and poor characteristics in another test. This observed variability in performance of different materials agrees with similar observations made by other investigations (4). This performance variation was also seen in all of the tests within a given generic type of chemical, such as within the epoxies, urethanes, methyl methacrylates, and masonry coatings.

Inspite of the fact that significant variations in performance existed, there were certain specific formulations of different materials that showed a relatively good performance in all of the tests in this project. Five different materials exhibited the following reductions in chloride intrusion and water absorption at the end of these different tests:

Material (% solids)	Percent Chloride Red. Rapid Perm.	Water Vapor	Accel. Weath.	% Wt. Gain Reduct.	Wt. Loss Wt. Gain Ratio, %	Comments (# of coats)
1-E (50)	85.8	78.0	82.3	92.8	420	slight etch & discolor (2)
10-S (40)	88.5	81.5	93.0	87.7	486	light etch (1)
11-Sc (5)	70.6	82.2	89.5	86.5	444	light etch (2)
14-Sx (20)	73.7	85.4	90.2	84.6	444	mod. etch (2)
25-E (100)	98.6	87.7	89.4	91.2	83	slight discolor (1)

These five material, two epoxies - 1 (50 percent solids) and 25 (100 percent solids), a silane - 10, a silicone - 11, and a siloxane - 14 provided a comparatively good performance through all the tests. Two of these materials, 10-S and 25-E, that exhibited good performance in all of the tests required only one coat, whereas the other three materials, 1-E, 11-Sc, and 14-Sx, required two coats.

The two epoxies, 1-E and 25-E, exhibited good performance characteristics when applied to concrete that had been allowed to air dry from 1 to 3 after the initial curing of 7 days according to the ACI (5). Three of the materials (classified as penetrants), 10-S, 11-Sc, and 14-Sx, were more effective when they were applied to concrete that had been allowed to cure for 28 days. These findings agreed with the recommendations of the respective manufacturers. However, the silicone (No. 11), exhibited only a slight decrease in its performance when it was applied to concrete in the early stages of the curing period.

The other epoxies, Nos. 2, 3, and 4, were similar to No. 1 in their chemical composition with the exception of their percent solids

contents (No. 2 - 20 % and Nos. 1, 3, and 4 - 50 %). The other silanes, Nos. 7, 8, and 9, were similar to No. 10 in their chemical composition with the exception of their percent active ingredients (Nos. 8 and 9 - 20 %, Nos. 7 and 10 - 40 %). Nos. 1-E and 10-S performed slightly better than the other materials of the same generic type as shown below.

Material (% solids)	Percent Chloride Reduct. Rapid Perm.	Water Vapor	Accel. Weath.	% Wt. Gain Reduct.	Wt. Loss Wt. Gain Ratio, %	Comments (# of coats)
1-E (50)	85.8	78.0	82.3	92.8	420	light etch & discolor (2)
2-E (20)	60.7	79.3	3.6	80.9	346	deep etch & discolor (1)
3-E (50)	90.0	44.0	86.9	81.3	292	light etch & discolor (1)
4-E (50)	88.3	83.0	70.6	95.6	467	light etch & discolor (2)
25-E (100)	98.6	87.7	89.4	91.2	83	slight discolor (1)
7-S (40)	83.0	80.8	91.1	76.6	231	light etch (1)
8-S (<20)	78.5	85.1	91.8	86.4	463	deep etch (1)
9-S (20)	61.1	65.4	88.3	71.0	230	light etch (1)
10-S (40)	88.5	81.5	93.0	87.7	486	light etch (1)

The performance of the epoxies and silanes was found to be related to the percent solids content or percent active ingredients. The materials with the higher solids content or active ingredients, on the average, performed considerably better than those with lower ones. This phenomena was observed throughout the entire project. The higher the percent solids content or active ingredients, the more material remaining on the concrete after the volatile portion

(thinners, driers, etc...) has evaporated. When this volatile portion evaporates, the remaining material on the surface of the concrete can shrink causing cracks and broken surfaces which can lead to increased chloride and water intrusion into the concrete (6).

Some of the materials, such as three epoxies (Nos. 2, 3, and 4), a urethane (No. 5), both methyl methacrylates (Nos. 12 and 13), and a blend of silanes (No. 18), did not provide the same consistent performance over all of the tests. Five out of seven of these specific materials (2-E, 4-E, 5-U, 12-MM, and 13-MM) provided good performance in the simple saltwater soaking test and the rapid chloride permeability test, but their performance was only poor to average in the accelerated weathering test. One material, 3-E, was very effective in the rapid chloride permeability and accelerated weathering tests, but poor in the saltwater soaking test. The blend of silanes, 18-BS, performed well in the saltwater soaking and the accelerated weathering tests, but poorly in the rapid chloride permeability test. This can be seen in the following table.

Material (% solids)	Percent Chloride Reduct. Rapid Perm.	Water Vapor	Accel. Weath.	% Wt. Gain Reduct.	Wt. Loss Wt. Gain Ratio, %	Comments (# of coats)
2-E (20)	60.7	79.3	3.6	80.9	346	deep etch & discolor (1)
3-E (50)	90.0	44.0	86.9	81.3	292	light etch & discolor (1)
4-E (50)	88.3	83.0	70.6	95.6	467	light etch & discolor (2)
5-U (55)	94.5	87.4	67.8	85.7	100	no change (1)
12-MM(20)	76.0	87.5	45.5	91.4	740	light etch & discolor (2)
13-MM(30)	78.6	73.5	3.1	60.5	187	mod. etch (2)
18-BS (30)	48.0	76.5	92.5	77.7	300	deep etch (2)

These poor performances in one of the three tests indicate that there is not just one test that can determine the performance of the coatings with a high degree of accuracy. Other tests should be run to verify the effectiveness of the coatings/sealers.

The following materials were suspect in their relative effectiveness in reducing saltwater absorption and chloride intrusion: an epoxy (2-E), a moisture-cured urethane (6-U), a straight methyl methacrylate (13-MM), a siloxane/silicone mixture (15-SS), and a poly-siloxane/fumed silica (21-PS). All six of the masonry coatings (Nos. 16, 19, 20, 22, 23, and 24) were also comparatively ineffective chloride barriers in each of the tests.

	Percent Chloride Reduct.			% Wt.	Wt. Loss	
Material (% solids)	Rapid Perm.	Water Vapor	Accel. Weath.	Gain Reduct.	Wt. Gain Ratio, %	Comments (# of coats)
2-E (20)	60.7	79.3	3.6	80.9	346	deep etch & discolor (1)
6-U (30)	35.5	21.1	30.2	32.4	125	deep etch (2)
13-MM(30)	78.6	73.5	3.1	60.5	187	mod. etch (2)
15-SS (10)	65.2	84.7	30.5	77.7	331	deep etch (2)
21-PS (7)	42.5	23.3	80.8	9.6	121	mod. etch (2)
16-MC	58.4	81.2	-14.0	56.8	173	deep etch (1)
19-MC	61.6	39.1	32.3	22.3	121	no change (1)
20-MC	60.2	62.7	31.6	76.0	247	no change (1)
22-MC	47.0	62.6	-24.9	65.7	175	light etch & discolor (2)
23-MC	51.6	18.3	30.9	42.8	114	no change (2)
24-MC	53.4	25.0	17.7	24.1	122	no change (2)

The masonry coatings did not, however, show the deterioration and discoloration that many of the other coatings did, with the exception of No. 16. Therefore, if esthetics is a desired feature of the

coating system and there is sufficient funding, then a masonry coating could be applied over a more effective sealer to provide a beautiful yet effective chloride barrier. Some study in this area should be undertaken to ascertain whether or not this is, in fact, a possible alternative.

Suggested Testing Methods

Basically three different test methods were used during this project. The rapid chloride ion permeability test required about eight weeks to complete, a simple saltwater soaking and drying test took around 13 weeks to finish, and a northern climate accelerated weathering test lasted for 24 weeks. These three test procedures could be used by testing laboratories, highway departments, and chemical manufacturers. The first two test procedures could be preliminary screening tests that would quickly and economically eliminate materials that should not be considered for the accelerated weathering tests. The first two tests can be run with low technical support and they are very easy to set up. These test procedures are as follows:

1. A preliminary screening test could be made on 2-in. cylinders using the rapid chloride permeability test. Another preliminary screening test could be made on 4-in. cubes using the simple saltwater soaking procedure. The concrete should be lightly sandblasted before the coating/sealer is applied. Special attention should be given to the degree of sandblastings, because over blasting can seriously damage the concrete surface and alter the results. The

materials should be brushed on according to the manufacturer's recommendations for coverage rate and minimum curing time prior to application. Special consideration for further testing should be given to those materials that excelled in one test and had slightly lower results in the other one. The rapid chloride permeability test is less reliable than the saltwater soaking and drying test and should be used only to verify the results from the latter test (7).

2. Following the above preliminary screening tests, an accelerated weathering test should be made with the acceptable coatings/sealers on concrete slabs that are subjected to either the 24 week northern or southern climate testing procedure. (The southern climate procedure consists of saltwater soaking for 100 hours at about 65 degrees F and then 68 hours of ultraviolet light at 100 degrees F. This testing procedure was not utilized in this project, because the northern climate testing procedure represented the typical weather in this area.) The appropriate accelerated weathering test procedure that should be followed depends on the climate of the particular area under concern.

CHAPTER 4
CONCLUSIONS, RECOMMENDATIONS, AND FUTURE STUDY

Conclusions

1. All of the materials performed better than the untreated control specimen. This conclusion held true for all but a few of the test results.

2. The epoxies were effective chloride and water absorption barriers, but did deteriorate and discolor slightly in the accelerated weathering test.

3. The penetrants (straight silanes, silicone, and siloxane) were relatively good in terms of their ability to resist water and chloride absorption. They also showed very little signs of deterioration in the weathering test. The materials that were combinations of the above penetrants did not perform as well as the straight penetrants.

4. The urethanes and methyl methacrylates did not perform consistently across all three tests. Their results varied dramatically from one test to another.

5. Masonry coatings were quite ineffective chloride barriers, but they do have esthetic qualities. This statement was confirmed across each of the different experiments.

6. The materials with the higher solids content or active ingredients performed better in all of the tests. This was found to be

true for the epoxies, silanes, and urethanes.

7. The rapid chloride permeability testing method is a quick test method. However, the results obtained from this test method were not consistent with the other tests conducted in this research.

8. It was found that the longer the curing period, the increased percent reduction of chloride permeability compared to the control.

Recommendations and Future Study

1. In spite of the fact that significant variations in performance existed among these 25 coatings, five specific formulations of different coating systems consistently demonstrated a comparatively distinguished performance from the others and a significant improvement from the non-coated control specimen.

The five coating systems are: No. 1 - Epoxy (50% solid), N0. 2 - Silane (40% active ingredients), No. 11 - Silicone (5% solid), No. 14 Siloxane (10% solids), No. 25 - Epoxy (100% solid). We recommend these five coatings to be added to the IDOH List of Approved Proprietary Portland Cement Concrete Sealers.

2. This study concluded that the epoxies were effective chloride and water absorption barriers, but deteriorate and discolor slightly in the accelerated weathering test. In contrast, masonry coatings were quite ineffective chloride barriers, but could preserve the coated color and hold concrete surface almost intact after long and severe accelerating weathering test. If aesthetics is a desired feature of the coating system,we recommend that a masonry system be

applied over epoxies or other good sealers which have proved quality in stopping chloride, moisture, or chemicals penetration.

3. As mentioned previously, we recommend two preliminary tests be run on materials to be evaluated - the water absorption/vapor transmission/chloride titration test and the chloride ion permeability test. The accelerated weathering test could then be run on the certain materials that performed well in the preliminary test for final approval or disapproval.

4. The experimental results confirmed and verified the minimum requirement of 3-days dry cure prior to the application of epoxies penetration sealers in the Standard Specification of Indiana Department of Highway (709.04-b-environmental requirements for epoxies penetrating sealers). Therefore, it is recommended that a minimum of 3-days dry cure after 4 days wet cure be needed before applying the epoxies on the new concrete surface; 3 days dry cure for old concrete.

5. There was no statistically significant difference on subjecting three different cure periods (at 9, 19, and 28 days age) for four different types of Alkyle-Alkoxy Silanes in Water Absorption/vapor Transmission Test of this study. A further study is recommended to determine a shorter cure period. Thus, a shorter construction time may be achieved.

6. Sandblasting newly placed concrete before adequate cure will excessively remove the very fine layer of paste on the new fresh concrete surface . The layer of paste retains moisture inside the concrete for hydration with cement. The removal of the layer causes the concrete upper surface to dry faster and leaves unhydrated

cement inside the concrete. The unhydrated cement will later react with the water, change the microstructure of concrete, and create new concrete surface which weakens the bond between the sealer and concrete.

It is recommended that sandblasting be done immediately prior to application of coating/sealer. The longer the concrete is cured, the harder the paste layer of concrete will be, the less paste will be sandblasted out, and the better the fine layer of paste and concrete cure will be. This procedure will not only avoid arbitrary judgement but will also save the time and cost of resandblasting.

7. In future research, it is recommended that the effects of ultraviolet radiation be determined on concrete with a surface coating/sealer applied on them. The U.V. source should be located as close as possible to the concrete in order to simulate as many exposure-days as feasible. The effects of the U.V. could be measured with a glossmeter color measuring, and/or brightness measuring instruments. The U.V. wavelengths that are particularly damaging to the coating/sealers should be determined. Also, some of the better quality coatings/sealers could be applied to concrete pavement to increase the life of the road. Tests would have to be run to determine the wear or abrasion resistance of the applied materials.

LIST OF REFERENCES

LIST OF REFERENCES

1. Wiss, Janney, Elstner and Associates, Inc., Concrete Sealers for Protection on Bridge Structures Report No. 244, National Cooperative Highway Research Program 12-19A, Washington, D.C., 1979, Wiss, Janney, Elstner and Associates, Inc., p. 2.

2. Interim Method of Test for Rapid Determination of Chloride Permeability of Concrete, AASHTO Designation: T 277-831, 1981.

3. Wiss, Janney, Elstner and Associates, Inc., Concrete Sealers for Protection on Bridge Structures Report No. 244, National Cooperative Highway Research Program 12-19A, Washington, D.C., 1979, Wiss, Janney, Elstner and Associates, Inc., p. 96.

4. Ibid, p. 9.

5. Mindess, Sidney and Young, Francis, J., Concrete, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1981, p. 305.

6. Smutzer, R. K., and Zander, A. D., A Field and Laboratory Evaluation of Various Portland Cement Concrete Sealers and Masonry Coating Systems Applied on Concrete Barrier Walls - Report No. 1, Division of Materials and Tests Special Studies Section, IDOH, 1987.

7. Whiting, D., Rapid Determination of the Chloride Permeability of Concrete, FHWA/RD-81/119, Washington, D.C., 1981.

8. Indiana Department of Highways Specifications, Section 702 - Structual Concrete, pp. 286-287, 1986.

9. Wiss, Janney, Elstner and Associates, Inc., Concrete Sealers for Protection on Bridge Structures Report No. 244, National Cooperative Highway Research Program 12-19A , Washington, D.C., 1979, Wiss, Janney, Elstner and Associates, Inc., p. 117.

10. Ibid, p. 118.

11. Ibid, p. 119.

12. Livtin, A.J., Clear Coatings for Exposed Architextural Concrete, Portland Cement Association, Research and Development, Vol. 10, No. 2 (1968), pp. 49-57.

13. Wiss, Janney, Elstner and Associates, Inc., Concrete Sealers for Protection on Bridge Structures Report No. 244, National Cooperative Highway Research Program 12-19A , Washington, D.C., 1979, Wiss, Janney, Elstner and Associates, Inc., p. 119.

GENERAL REFERENCES

1. Indiana Department of Highways Specifications, Section 702 - Structural Concrete, Section 903 - Aggregates, 1986.

2. Florida Department of Transportation, Qualified Products List, 1987.

3. Kentucky Department of Transportation Specifications, Section 828 - Masonry Coating Materials and Approved List, 1985.

4. Resistance of Concrete to Rapid Freezing and Thawing, ASTM Designation C666, 1984.

5. Rapid Determination of the Chloride Permeability of Concrete, Report No. FHWA/RD-81/119, 1981.

6. Burstrom, P.G., Durability and Aging of Sealants, Durability of Building Materials and Components, ASTM STP 691, 1980.

7. Fletcher, John F., Instruments for Coating Inspection, Journal of Protective Coatings and Linings, May 1986.

8. Gaul, Robert W., Preparing Concrete Surfaces for Coatings, Concrete International, July 1984.

9. Gausman, Robert, New Materials for Painting Highway Structures, Journal of Protective Coatings and Linings, March 1986.

10. Litvin, A., Clear Coatings for Exposed Architectural Concrete, J. Portland Cement Association, Research and Development, Vol. 10, No. 2 (1968).

11. Maslow, Philip, Chemical Materials for Construction, McGraw-Hill, Inc., 1982.

12. Mindess, Sidney and Young, Francis, J., Concrete, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1981.

13. Munger, Charles G., Corrosion Prevention by Protective Coatings, National Association of Corrosion Engineers, Houston, Texas, 1984.

14. Stavincha, Ray, Protecting Concrete from Exposure to Aggressive Chemicals, Journal of Protective Coatings and Linings, February 1988.

15. Wiss, Janney, Elstner and Associates, Inc., Concrete Sealers for Protection on Bridge Structures Report No. 244, National Cooperative Highway Research Program 12-19A , Washington, D.C., 1979, Wiss, Janney, Elstner and Associates, Inc.

APPENDICES

Appendix A
Selection of Candidate Materials

An extensive literature search was completed in the Potter Engineering library at Purdue University using Thomas' Register and Sweets Manual. Also reviewed was information and literature received from the Indiana, Ohio, Tennessee, Illinios, Kentucky, Texas, and Florida state departments of transportation. This search revealed the concrete sealer/coatings presently being utilized by the above states. A questionnaire regarding the technical data of concrete sealers was sent to 119 chemical companies. Product information received from 54 out of 119 suppliers of coatings that answered the questionnaire was analyzed. From the 54 chemical companies that responded, 42 companies suggested 120 different materials.

Review of the information and literature received from the departments of transportation of Indiana and the surrounding states indicated that epoxy is one of the most widely used sealant materials. The solids content was generally in the range of 15 to 100 percent. They have been tested by many departments of transportation and independent laboratories and are being used by many states. Two coats are usually recommended to insure sufficient protection. The opinions of the surrounding state departments of transportation are consistent in that they feel very confident about using epoxy as a sealer.

Many of these departments of transportation have been testing

por permeation or breathing. Many of these state DOTs also feel that this material is an excellent concrete sealer. Siloxane is another

A few of the other generic types that are being used by the surrounding states are as follows: methyl methacrylate, elastomer/polyester, acrylic polymer, polyester resin, and vinyl acrylic latex. All of the above materials are being thoroughly tested both in the field and the laboratory by many state departments of transportation and independent laboratories.

Many of the chemical companies submitted data on the following tests: chloride-ion penetration, freeze/thaw, accelerated weathering, salt resistance, etc.... These tests were done by National Cooperative Highway Research Program (NCHRP 244), state departments of transportation, and independent testing laboratories. This data weighed heavily in determining the samples that would be selected for further testing. From the submitted information and data, 24 coatings or penetrants were selected from different chemical companies which generally include all of the generic types of materials most widely used today. These were as follows:

	Test No.
Epoxies:	
Five epoxies with varying percent solids	1,2,4,25,26
One epoxy containing polysulfide	3
Penetrants:	
Four alkyl-alkoxy silanes	7,8,9,10

Silicone	11
Siloxane	14
A siloxane/silicone combination	15
Poly-siloxane/hydrophobic-fumed silica	21
Combination of many forms of silane	18
Masonry Coatings:	
Styrene Acrylic copolymer	16,22
Elastomer/polyester	17
Vinyl acrylic latex	19
Polyester resin	20
Elastomeric acrylic	23
Acrylic resin	24
Other:	
Two types of urethane	5,6
Two materials based on methacrylate	12,13

Table A-1 identifies the materials and their assigned test number. Tables A-2 through A-23 provide the technical data and the manufacturer's application data.

Table A-1

Materials Selected for Testing

Test No.	Chemical Composition	Percent solids	Penetrant or coating
1	Epoxy (polyamine)	50	P
2	Epoxy (polyamine)	20	P
3	Epoxy (polysulfide)	50	P
4	Epoxy (polyamine)	50	P
5	Chemically-cured urethane	55	C
6	Moisture-cured urethane	30	P
7	Alkyl-Alkoxy silane	40	P
8	Alkyl-Alkoxy silane	<20	P
9	Alkyl-Alkoxy silane	20	P
10	Alkyl-Alkoxy silane	40	P
11	Silicone	5	P
12	Methyl methacrylate with silane primer	20	P
13	Methyl methacrylate	30	P
14	Siloxane	20	P
15	Siloxane/Silicone mixture	10	P
16	Styrene/Acrylic Copolymer	75	C
18	Blend of silanes	30	P
19	Vinyl acrylic latex	58	C
20	Polyester resin	60	C
21	Poly-siloxane/hydrophobic fumed silica	7	P
22	Styrene/Acrylic Copolymer	61	C
23	Elastomeric resin		C
24	Acrylic resin		C
25	Epoxy	100	C

Table A-2

Material No. 1
Chemical Composition: Epoxy penetrant

Technical Data		Application Data	
Solids (minimum % by weight):	50	Weight (lb per gallon):	8.1
Specific Gravity:	1	Number of Coats:	1 or 2
Viscosity:	15-40 cps	Primer Required:	No
pH:	N/A	Time Between Coats:	N/A
Color:	Clear	Coverage Rate (sf/gallon):	150-250
Boiling Point:	260-285 F	Drying Time to Touch:	4 hr
Flash Point:	90 F	Drying Time to Set:	4-6 hr
Minimum Cure of Concrete:	3 Days	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Flammable. Use proper ventilation, gloves, and goggles.		Limitations: Apply above 45 degrees F.Do not apply when rain is expected. Surface must be clean. Use only on non-wearing surfaces.	

Table A-3

Material No. 2
Chemical Composition: Epoxy penetrant

Technical Data		Application Data	
Solids (minimum % by weight):	20	Weight (lb per gallon):	9.8
Specific Gravity:	H-0.92	Number of Coats:	1
Viscosity:	Low	Primer Required:	No
pH:	N/A	Time Between Coats:	N/A
Color:	Lt. Amber	Coverage Rate (sf/gallon):	200
Boiling Point:	N/A	Drying Time to Touch:	1.5-2 hr
Flash Point:	90 F	Drying Time to Set:	4-5 hr
Minimum Cure of Concrete:	7 Days	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Flammable. Use proper ventilation, gloves, and goggles. Avoid contact with skin.		Limitations: Remove all loose material and spalled concrete. Surface must be free of oil, dirt, grease, and other surface coatings. Apply on dry and frost free surfaces.	

Table A-4

Material No. 3

Chemical Composition: Epoxy penetrant

Technical Data		Application Data	
Solids (minimum % by weight):	50	Weight (lb per gallon):	8.3
Specific Gravity:	N/A	Number of Coats:	1
Viscosity:	30 cps	Primer Required:	No
pH:	N/A	Time Between Coats:	N/A
Color:	Clear Amber	Coverage Rate (sf/gallon):	80-125
Boiling Point:	110	Drying Time to Touch:	N/A
Flash Point:	45	Drying Time to Set:	4-6 hr
Minimum Cure of Concrete:	21 Days	S=Spray, R=Roll, B=Brush:	R,B
Precautions: Flammable. Use proper ventilation, gloves, and goggles. Avoid contact with skin.		Limitations: Apply at 50 degrees F or above. Surface must be clean, dry and free of oil, dirt, grease, and other surface coatings. Sand or waterblast if necessary.	

Table A-5

Material No. 4
Chemical Composition: Epoxy penetrant

Technical Data		Application Data	
Solids (minimum % by weight):	50	Weight (lb per gallon):	9.8
Specific Gravity:	N/A	Number of Coats:	2
Viscosity:	15-40 cps	Primer Required:	No
pH:	N/A	Time Between Coats:	N/A
Color:	Amber/Gray	Coverage Rate (sf/gallon):	100-150
Boiling Point:	N/A	Drying Time to Touch:	N/A
Flash Point:	N/A	Drying Time to Set:	3-4 hr
Minimum Cure of Concrete:	4 Days	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Flammable. Use proper ventilation, gloves, and goggles. Avoid contact with skin.		Limitations: The pH of surface should be aournd 10. Surface must be clean, dry and free of oil, dirt, grease, and other surface coatings. Sand or waterblast if necessary.	

Table A-6

Material No. 5
Chemical Composition: Urethane

Technical Data		Application Data	
Solids (minimum % by weight):	55	Weight (lb per gallon):	10.8
Specific Gravity:	N/A	Number of Coats:	1
Viscosity:	70-75 cps	Primer Required:	No
pH:	N/A	Time Between Coats:	N/A
Color:	Gray	Coverage Rate (sf/gallon):	250-350
Boiling Point:	N/A	Drying Time to Touch:	4-5 hr
Flash Point:	75F	Drying Time to Set:	12-16 hr
Minimum Cure of Concrete:	1 Day	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Flammable. Use proper ventilation, gloves, and goggles. Avoid contact with skin.		Limitations: Apply between the temperatures of 50 and 120 degrees F and at less than 80 % RH. Surface must be absolutely dry and clean.	

Table A-7

Material No. 6
Chemical Composition: Urethane (moisture-cured)

Technical Data		Application Data	
Solids (minimum % by weight):	30	Weight (lb per gallon):	8.5
Specific Gravity:	1	Number of Coats:	1 to 3
Viscosity:	500 cps	Primer Required:	N/A
pH:	8.5	Time Between Coats:	1 hr
Color:	Clear	Coverage Rate (sf/gallon):	300-400
Boiling Point:	212 F	Drying Time to Touch:	1 hr
Flash Point:	212 F	Drying Time to Set:	1-2 days
Minimum Cure of Concrete:	1 Day	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Use proper ventilation, gloves, and goggles.		Limitations: Remove contaminants which may interfere with adhesion.	

Table A-8

Material No. 7
Chemical Composition: Alkyl-Alkoxy Silane

Technical Data		Application Data	
Solids (minimum % by weight):	40	Weight (lb per gallon):	7.01
Specific Gravity:	0.8	Number of Coats:	1
Viscosity:	N/A	Primer Required:	N/A
pH:	6.5	Time Between Coats:	N/A
Color:	Clear	Coverage Rate (sf/gallon):	125
Boiling Point:	174 F	Drying Time to Touch:	2 hr
Flash Point:	54 F	Drying Time to Set:	4 hr
Minimum Cure of Concrete:	28 Days	S=Spray, R=Roll, B=Brush:	S
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Surfaces need not be completely dry before application; however, must be clean, and standing water must be removed. Should not be applied at or below 32 degrees F.	

Table A-9

Material No. 8
Chemical Composition: Alkyl-Alkoxy Silane

Technical Data		Application Data	
Solids (minimum % by weight):	<20	Weight (lb per gallon):	7.48
Specific Gravity:	0.89	Number of Coats:	1
Viscosity:	33 cps	Primer Required:	N/A
pH:	N/A	Time Between Coats:	N/A
Color:	White	Coverage Rate (sf/gallon):	125
Boiling Point:	318 F	Drying Time to Touch:	1 hr
Flash Point:	106 F	Drying Time to Set:	12 hr
Minimum Cure of Concrete:	28 Days	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Surface should be free from dirt, oil, grease, concrete curing residue, paint, and/or other foreign materials. Do not apply to frost covered or permeated surfaces. Application to inadequately cleaned or damp concrete will result in less than optimum penetration and protection performance.	

Table A-10

Material No. 9
Chemical Composition: Alkyl-Alkoxy Silane

Technical Data		Application Data	
Solids (minimum % by weight):	20	Weight (lb per gallon):	7.2
Specific Gravity:	0.97	Number of Coats:	1
Viscosity:	N/A	Primer Required:	N/A
pH:	N/A	Time Between Coats:	N/A
Color:	White	Coverage Rate (sf/gallon):	125
Boiling Point:	212 F	Drying Time to Touch:	N/A
Flash Point:	145 F	Drying Time to Set:	6 hr
Minimum Cure of Concrete:	28 Days	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Surface should be free from dirt, oil, grease, concrete curing residue, paint, and/or other foreign materials. Do not apply to frost covered or permeated surfaces. Application to inadequately cleaned or damp concrete will result in less than optimum penetration and protection performance.	

Table A-11

Material No. 10
Chemical Composition: Alkyl-Alkoxy Silane

Technical Data		Application Data	
Solids (minimum % by weight):	40	Weight (lb per gallon):	7.4
Specific Gravity:	0.797	Number of Coats:	1
Viscosity:	0.974 cent	Primer Required:	N/A
pH:	Neutral	Time Between Coats:	N/A
Color:	White	Coverage Rate (sf/gallon):	125
Boiling Point:	310-375 F	Drying Time to Touch:	1-2 hr
Flash Point:	105 F	Drying Time to Set:	4-6 hr
Minimum Cure of Concrete:	14 Days	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Surface should be free from dirt, oil, grease, concrete curing residue, paint, and/or other foreign materials. Do not apply to frost covered or permeated surfaces. Apply above 14 degrees F. Avoid application on extremely hot and windy days.	

Table A-12

Material No. 11
Chemical Composition: Silicone

Technical Data		Application Data	
Solids (minimum % by weight):	5	Weight (lb per gallon):	7.3
Specific Gravity:	0.795	Number of Coats:	2
Viscosity:	0.986 cent	Primer Required:	N/A
pH:	Neutral	Time Between Coats:	0.5 hr
Color:	White	Coverage Rate (sf/gallon):	100-200
Boiling Point:	310-375 F	Drying Time to Touch:	1 hr
Flash Point:	105 F	Drying Time to Set:	4 hr
Minimum Cure of Concrete:	28 days	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Surface must be clean and dry to allow penetration. All membrane cures are to be removed. Do not apply at temperatures below 50 degrees F.	

Table A-13

Material No. 12
Chemical Composition: Methyl Methacrylate

Technical Data		Application Data	
Solids (minimum % by weight):	20	Weight (lb per gallon):	8.1
Specific Gravity:	N/A	Number of Coats:	2
Viscosity:	N/A	Primer Required:	N/A
pH:	N/A	Time Between Coats:	N/A
Color:	Amber	Coverage Rate (sf/gallon):	100-200
Boiling Point:	228-285 F	Drying Time to Touch:	N/A
Flash Point:	40 F	Drying Time to Set:	2 hr
Minimum Cure of Concrete:	1day	S=Spray, R=Roll, B=Brush:	S,R
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Surface must be free of dirt,oil, grease, sealers, and other contaminants. May be applied to damp surfaces provided that no liquid water exists. Apply between the temperatures of 40 and 90 degrees F.	

Table A-14

Material No. 13
Chemical Composition: Methyl Methacrylate

Technical Data		Application Data	
Solids (minimum % by weight):	30	Weight (lb per gallon):	7.8
Specific Gravity:	0.91	Number of Coats:	2
Viscosity:	A Gardner	Primer Required:	N/A
pH:	Neutral	Time Between Coats:	0.5 hr
Color:	White	Coverage Rate (sf/gallon):	300-400
Boiling Point:	305-355 F	Drying Time to Touch:	1 hr
Flash Point:	105 F	Drying Time to Set:	1 hr
Minimum Cure of Concrete:	1 day	S=Spray, R=Roll, B=Brush:	S,R
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Surface must be free of dirt, oil, grease, sealers, and other contaminants. Avoid applying in subfreezing weather or over standing water.	

Table A-15

Material No. 14
Chemical Composition: Siloxane

Technical Data		Application Data	
Solids (minimum % by weight):	20	Weight (lb per gallon):	7.4
Specific Gravity:	0.818	Number of Coats:	2
Viscosity:	N/A	Primer Required:	N/A
pH:	N/A	Time Between Coats:	0.5 hr
Color:	Clear	Coverage Rate (sf/gallon):	200
Boiling Point:	300 F	Drying Time to Touch:	N/A
Flash Point:	100 F	Drying Time to Set:	4 hr
Minimum Cure of Concrete:	14 days	S=Spray, R=Roll, B=Brush:	S,R
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Surface must be free of dirt, oil, grease, sealers, and other contaminants.	

Table A-16

Material No. 15
Chemical Composition: Siloxane/Silicone

Technical Data		Application Data	
Solids (minimum % by weight):	10	Weight (lb per gallon):	7.4
Specific Gravity:	0.855	Number of Coats:	2
Viscosity:	0.964 cent	Primer Required:	N/A
pH:	Neutral	Time Between Coats:	0.5 hr
Color:	White	Coverage Rate (sf/gallon):	200
Boiling Point:	310-375 F	Drying Time to Touch:	0.5 hr
Flash Point:	105 F	Drying Time to Set:	1 hr
Minimum Cure of Concrete:	14 days	S=Spray, R=Roll, B=Brush:	S,R
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Surface must be free of dirt, oil, grease, sealers, and other contaminants. Apply at 40 degrees F or above and avoid applying on hot and windy days.	

Table A-19

Material No. 19
Chemical Composition: Vinyl Acrylic Latex

Technical Data		Application Data	
Solids (minimum % by weight):	58	Weight (lb per gallon):	10.5
Specific Gravity:	N/A	Number of Coats:	1
Viscosity:	104-110 KU	Primer Required:	N/A
pH:	9-Aug	Time Between Coats:	N/A
Color:	White	Coverage Rate (sf/gallon):	50
Boiling Point:	N/A	Drying Time to Touch:	3 hr
Flash Point:	201 F	Drying Time to Set:	4 hr
Minimum Cure of Concrete:	1 day	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: The concrete surface must be clean, cool, dry, free of grease, scaly paint, or other foreign materials. The pH of the concrete must be in the range of 4 to 9. Do not apply below 45 degreees F or when the temperature may drop below 45 F within the next 24 hours.	

Table A-18

Material No. 18
Chemical Composition: Blend of Silanes

Technical Data		Application Data	
Solids (minimum % by weight):	30	Weight (lb per gallon):	6.8
Specific Gravity:	0.816	Number of Coats:	1
Viscosity:	2.02 cps	Primer Required:	N/A
pH:	6	Time Between Coats:	N/A
Color:	Clear	Coverage Rate (sf/gallon):	125
Boiling Point:	300 f	Drying Time to Touch:	24 hr
Flash Point:	100 F	Drying Time to Set:	72 hr
Minimum Cure of Concrete:	28 days	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Application temperature, material, and substrate must be 50 degrees F or above. Surface must be clean and dry. Sand or water blast if necessary.	

Table A-17

Material No. 16
Chemical Composition: Styrene/Acrylic Copolymer

Technical Data		Application Data	
Solids (minimum % by weight):	75	Weight (lb per gallon):	10.3
Specific Gravity:	1.24	Number of Coats:	1
Viscosity:	>130	Primer Required:	N/A
pH:	N/A	Time Between Coats:	N/A
Color:	Clear	Coverage Rate (sf/gallon):	50
Boiling Point:	300-400 F	Drying Time to Touch:	3 hr
Flash Point:	105 F	Drying Time to Set:	6 hr
Minimum Cure of Concrete:	1 day	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Cannot be applied over other curing membranes. Surface may require a light sand or waterblast to insure that residual curing membranes are removed. Minor surface imperfections need not be repaired. Must be free of oil, dirt, asphalt, mud and loose, scaly, powdery substances.	

Table A-20

Material No. 20
Chemical Composition: Alkyd Polyester

Technical Data		Application Data	
Solids (minimum % by weight):	60	Weight (lb per gallon):	9.4
Specific Gravity:	1.13	Number of Coats:	1
Viscosity:	40-45 sec	Primer Required:	N/A
pH:	N/A	Time Between Coats:	N/A
Color:	Gray	Coverage Rate (sf/gallon):	50
Boiling Point:	314-399 F	Drying Time to Touch:	2-3 hr
Flash Point:	105 F	Drying Time to Set:	6-8 hr
Minimum Cure of Concrete:	28 days	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Do not apply when rain or freezing conditions are imminent. Apply between the temperatures of 45 and 100 degrees F. Surface must be free from efflorescence coatings, dirt, oil, and other substances.	

Table A-21

Material No. 21
Chemical Composition: Poly-Siloxane/Fumed-Silica

Technical Data		Application Data	
Solids (minimum % by weight):	7	Weight (lb per gallon):	6.8
Specific Gravity:	N/A	Number of Coats:	1
Viscosity:	N/A	Primer Required:	N/A
pH:	N/A	Time Between Coats:	N/A
Color:	Frosty	Coverage Rate (sf/gallon):	200-300
Boiling Point:	250 F	Drying Time to Touch:	N/A
Flash Point:	102 F	Drying Time to Set:	1 hr
Minimum Cure of Concrete:	28 days	S=Spray, R=Roll, B=Brush:	S
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Surface must be free of dirt, oil, grease, paint, and other contaminants. Not for use below grades or on horizontal surfaces.	

Table A-22

Material No. 22

Chemical Composition: Styrene/Acrylic Copolymer

Technical Data		Application Data	
Solids (minimum % by weight):	61	Weight (lb per gallon):	10.5
Specific Gravity:	N/A	Number of Coats:	1 or 2
Viscosity:	115 KU	Primer Required:	N/A
pH:	N/A	Time Between Coats:	6 hr
Color:	White	Coverage Rate (sf/gallon):	624
Boiling Point:	N/A	Drying Time to Touch:	3-4 hr
Flash Point:	140 F	Drying Time to Set:	1-2 days
Minimum Cure of Concrete:	28 days	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Not recommended for wood or unprimed metal surfaces. Applying at temperatures below 60 degrees F will result in greatly prolonged drying and curing periods.	

Table A-23

Material No. 23
Chemical Composition: Elastomeric Acrylic Resin

Technical Data		Application Data	
Solids (minimum % by weight):	N/A	Weight (lb per gallon):	13
Specific Gravity:	N/A	Number of Coats:	1 or 2
Viscosity:	N/A	Primer Required:	No
pH:	N/A	Time Between Coats:	1 hr
Color:	White	Coverage Rate (sf/gallon):	50-125
Boiling Point:	N/A	Drying Time to Touch:	1 hr
Flash Point:	N/A	Drying Time to Set:	4-6 hr
Minimum Cure of Concrete:	28 days	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Apply above 40 degrees F. Do not apply when rain is expected. Sealer must be thoroughly mixed.	

Table A-24

Material No. 24
Chemical Composition: Resin-Based

Technical Data		Application Data	
Solids (minimum % by weight):	N/A	Weight (lb per gallon):	13
Specific Gravity:	N/A	Number of Coats:	1 or 2
Viscosity:	N/A	Primer Required:	No
pH:	N/A	Time Between Coats:	1 hr
Color:	White	Coverage Rate (sf/gallon):	50-125
Boiling Point:	N/A	Drying Time to Touch:	1 hr
Flash Point:	N/A	Drying Time to Set:	4-6 hr
Minimum Cure of Concrete:	28 days	S=Spray, R=Roll, B=Brush:	S,R,B
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Apply above 40 degrees F. Do not apply when rain is expected. Sealer must be thoroughly mixed.	

Table A-25

Material No. 25
Chemical Composition: Epoxy

Technical Data		Application Data	
Solids (minimum % by weight):	100	Weight (lb per gallon):	15
Specific Gravity:	N/A	Number of Coats:	1
Viscosity:	N/A	Primer Required:	No
pH:	N/A	Time Between Coats:	10 min
Color:	Gray	Coverage Rate (sf/gallon):	50-125
Boiling Point:	N/A	Drying Time to Touch:	10 min
Flash Point:	N/A	Drying Time to Set:	1 hr
Minimum Cure of Concrete:	28 days	S=Spray, R=Roll, B=Brush:	R,B
Precautions: Use proper ventilation, gloves, and goggles. Flammable.		Limitations: Apply above 40 degrees F. Do not apply when rain or frost is expected. Epoxy harders within minutes. Surface must be clean and dry.	

Appendix B
Chloride Ion Permeability - Phase II

Test Objective

The objectives of the chloride ion permeability test is to determine the ability of the sealers/coatings that are applied to the concrete to prevent penetration of chloride ions and to ascertain at what stage during the curing period coating the concrete with penetrating epoxies is most effective.

Theoretical Background

It has been shown in some recent studies that chloride can be caused to migrate out of a concrete slab quite rapidly under the application of an external field imposed across a concrete slab (7). This technique could be utilized as a chloride permeability method if the polarity were reversed by having a sodium hydroxide solution (+) on one side and a sodium chloride solution (-) on the other. The chloride ions would migrate into the concrete under the influence of an electric field. As the electrical resistivity of the concrete decreases with the increasing chloride ion concentration, a measure

of the increase in current with the time could be correlated with the amount of chloride entering the concrete.

The relationship between the chloride permeability and charge passed (coulombs) given in Table B-1 of AASHTO T 277-83I is reproduced below (2).

Table B-1 Chloride Permeability Based on Charge Passed

Charge Passed %(coulombs)	Chloride Permeability	Typical of
>4,000	High	High water-cement ratio, conventional (>0.6) PCC.
2,000-4,000	Moderate	Moderate water-cement ratio, conventional (0.4-0.5) PCC.
1,000-2,000	Low	Low water-cement ratio, conventional (<0.4) PCC.
100-1,000	Very Low	Latex-modified concrete Internally sealed concrete
<100	Negligible	Polymer impregnated concrete

Test Materials

The concrete was designed to meet the requirements of the Indiana Department of Highway specifications for Class A concrete (8). The test concrete was designed to have a w/c ratio no greater than 0.66, an air content between 5 and 8 percent, a ratio of fine

aggregate to total aggregate between 35 and 45 percent (by weight), and a slump of approximately 3.0 in.

The significant properties of the concrete and its materials were as follows:.

Portland cement	Type I
Air-entraining agent, ml	205
Cement content, lb	564
Fine aggregate, lb	1350
Coarse aggregate, lb	1850
Fine/Total aggregate, %	40.4
Water content, lb	312
Air content, %	6.5
W/C (by weight), %	52.7
Slump, in.	3.25
Absorption of fines, %	0.56
Absorption of coarse, %	1.15

Sample Preparation

The fresh concrete was placed inside 3.75 in. diameter 6 in. tall oiled molds in three layers, each layer rodded 25 times with a 3/8 in. diameter rod.

The cylinders were cured for 24 hours in the molds. The cylinders were then removed from the molds and placed in lime-saturated water for three days. At the age of five days, the cylinders

were cut into 2 inch disks. The flat surfaces of the cylinders were lightly sandblasted to remove the cement skin which would normally wear off by weathering.

The cylinders were allowed to cure until the age of seven days. At this time, six cylinders were set aside; five to be coated with the penetrating epoxies and one for an untreated control specimen. Material Nos. 1, 2, 3, 4, and 26 were the five epoxies. At the age of 14 days, six more cylinders were set aside; again, five to be coated with the penetrating epoxies and one for an untreated control specimen. At the age of 28 days, the remaining cylinders were coated with all of the materials.

The amount of material used to coat all of the cylinders as determined by the IDOH was 100 sf/gal and was applied in one coat with a brush. The sealers/coatings that were applied to the cylinders were allowed to cure for an additional seven days in a laboratory environment (73F and 20%RH) before the testing began.

Test Procedure (AASHTO Designation: T 277-83I)

According to the above AASHTO Designation, approximately 10 grams of rapid setting epoxy was prepared and brushed onto the sides of the cylinders. After the epoxy-covered surface had become tack-free, the cylinder was placed in a 1,000 ml beaker and the beaker placed in a vacuum desiccator. The desiccator was then sealed and the vacuum pump turned on. The vacuum was maintained for three hours.

At the end of three hours, previously boiled deionized water was allowed to cover the cylinder while maintaining the vacuum. The vacuum pump was run for an additional hour, after which the pump was shut off and the cylinder was allowed to soak in water for 18 more hours in a laboratory environment.

The cylinder was then mounted on the test cells and sealed with a silicone sealant in order to insure that there was no leakage of the solution during the test. The negative test cell was filled with a 3.0 percent NaCl solution. The positive test cell was filled a 0.3N NaOH solution. The lead wires were then attached to the respective test cells and the power supply was then turned on.

The test involved subjecting a saturated concrete sample mounted in the test cell to a 60 volt DC potential from end to end of the sample. This potential forces the migration of ions towards the electrode of opposite sign and the resulting current is recorded over a six hour span. The current flow is then integrated relative to time to give coulombs, the parameter relative to permeability.

This integration is done automatically by the Model 159 Test Set produced by RLC Instrument Co., Akron, Ohio. This particular instrument is capable of measuring one sample at a time. It generates the printout of time, current, and coulombs at 30 minute intervals and automatically terminates the test at the end of six hours.

Potential Sources of Errors

- The cylinders may not have been exactly two inches in depth due to the cutting procedure. This could have lead to slightly higher or lower chloride permeability values depending on the size.

- The cylinders were lightly sandblasted on the two flat sides. The amount of sandblasting done on each cylinder could have varied slightly which could also have led to variations in the results.

- Some settling of the larger aggregates may have occured in the six in cylinders, but this was believed to be minimal.

- It has been well documented that this method of testing has a fairly high degree of variability from test to test (around 20%). (6)

Discussion of Test Results

Tables B-2 and B-3 show the results of the chloride permeability tests in order of increasing permeability. Table B-2 gives the results of the chloride permeability testing on the five penetrating epoxies and the control specimen that were allowed to air dry for four days (coated at age seven days). Table B-2 also shows the results of the same six samples that air dried for 11 days (coated at age14 days) and 24 days (coated at age 28 days). Table B-3 gives the results of all of the samples that air dried 24 days (coated at age 28 days) and are depicted graphically in Figure B-1.

Table B-2

Rapid Chloride Permeability Results - AASHTO T 277-83I
Penetrating Epoxies Tested at 7, 14, and 28 Days

Coated at 7 Days

Sample Number	Generic Type (% solids)	Coulombs Passed	Percent Reduction	AASHTO Designation
3	Epoxy (50)	1061	52.9	low
4	Epoxy (50)	1396	39.2	low
26	Epoxy (50)	1689	25.0	low
1	Epoxy (50)	1718	23.7	low
2	Epoxy (20)	1914	15.0	low
*CONTROL	-----	2251	----	moderate

Coated at 14 Days

Sample Number	Generic Type (% solids)	Coulombs Passed	Percent Reduction	AASHTO Designation
4	Epoxy (50)	226	90.9	very low
3	Epoxy (50)	527	78.8	very low
1	Epoxy (50)	607	75.6	very low
26	Epoxy (50)	978	60.7	very low
2	Epoxy (20)	1437	42.3	low
*CONTROL	-----	2491	----	moderate

Coated at 28 Days

Sample Number	Generic Type (% solids)	Coulombs Passed	Percent Reduction	AASHTO Designation
3	Epoxy (50)	467	90.0	very low
26	Epoxy (50)	509	89.1	very low
4	Epoxy (50)	546	88.3	very low
1	Epoxy (50)	661	85.8	very low
2	Epoxy (20)	1829	60.7	low
*CONTROL	-----	**4657	----	high

* Two control specimens were tested and their values averaged for each test.

** The permeability of control should have decreased with increasing curing time.

Testing at IDOH has produced results from 1230 to 3075 coulombs on the control specimens. Refer to reference No. 6.

Table B-3

Rapid Chloride Permeability Results - AASHTO T 277-83I
All Materials

28 Days Air Drying

Sample Number	Generic Type (% solids)	Coulombs Passed	Percent Reduction	AASHTO Designation
25	Epoxy (100)	66	98.58	negligible
5	Urethane (55)	258	94.46	very low
3	Epoxy (50)	467	89.97	very low
26	Epoxy (50)	509	89.07	very low
10	Silane (40)	538	88.45	very low
4	Epoxy (50)	546	88.28	very low
1	Epoxy (50)	661	85.81	very low
7	Silane (40)	792	82.99	very low
13	Methyl Methacrylate (30)	997	78.59	very low
8	Silane (<20)	1002	78.48	low
12	Methyl Methacrylate (20)	1117	76.01	low
14	Siloxane (20)	1226	73.67	low
11	Silicone (5)	1369	70.60	low
15	Siloxane/Silicone (10)	1623	65.15	low
19	Vinyl Acrylic (58)	1788	61.61	low
9	Silane (20)	1812	61.09	low
2	Epoxy (20)	1829	60.73	low
20	Polyester Resin (60)	1853	60.21	low
16	Styrene Acrylic Cop. (61)	1939	58.36	low
24	Acrylic Resin	2170	53.40	moderate
23	Elastomeric Acrylic	2255	51.58	moderate
18	Blend of Silanes (30)	2421	48.01	moderate
22	Styrene Acrylic Cop. (75)	2470	46.96	moderate
21	Poly-siloxane/silica (7)	2680	42.45	moderate
6	Urethane (30)	3006	35.45	moderate
*CONTROL	-----	**4657	-----	high

* Two control specimens were tested and their values averaged for this test.
** The permeability of control should have decreased with increasing curing time.
*** Testing at IDOH has produced results from 1230 to 3075 coulombs on the control specimens. Refer to reference No. 6.

The following subsections discuss the ability of each generic type to resist chloride ion penetration.

Epoxies. Sample No. 25 with a 100 percent solids content had the lowest chloride permeability at 66 coulombs or a negligible rating. The five penetrating epoxies (Nos. 1, 2, 3, 4, and 26) had the lowest chloride permeability values when allowed to air dry 11 days or coat at age 14 days. Of the penetrating epoxies, the materials with the 50 percent solids contents were more effective at reducing chloride intrusion than the 20 percent solids epoxy in all three of the tests. Material No. 2, the 20 percent epoxy, had a rating of low in all three tests while the other four materials had very low ratings in the second and third tests and only low ratings in the first test.

Urethanes. Sample No. 5, the chemically-cured urethane with 55 percent solids, had a very low permeability rating and ranked second in the 28 day test. The moisture-cured urethane, No. 6, had a moderate rating, but was only better than the control specimen.

Silanes. Two materials, Nos. 7 and 10, had chloride permeability ratings of very low and sample No. 8 was right on the border of a very low and low rating. Material No. 9 had the worst rating of the four silanes at 1812 coulombs. The ability of the silanes to resist chloride intrusion appears to be related to the solids content also. Material No. 10 (40 percent solids) was over three times more effective than the 20 percent solids (No. 9).

Silicone. Material No. 11 had a low permeability rating and reduced the chloride content by over 70 percent compared to the control specimen.

Methyl Methacrylate. Material No. 13, the straight methyl methacrylate, reduced the chloride penetration by over 78 percent compared to the control, while the other material with the silane primer, No. 12, was just over 76 percent effective. Material No. 13 received a very low permeability rating and No. 12 got a low rating.

Siloxane. Material No. 14 had a low permeability rating and reduced the chloride intrusion by around 74 percent compared to the control.

Siloxane/Silicone. Sample No. 15, a mixture of siloxane and silicone, also had a low rating, but was only 65 percent more effective than the untreated control specimen.

Blend of Silanes. Material No. 18 had moderate resistance to chloride permeability and was less than half as effective as the control sample.

Poly-Siloxane/Fumed-Silica. Sample No. 21, a mixture of a poly-siloxane/fumed silica, was only 42 percent more effective against chloride permeation than the control and received a moderate rating.

Masonry Coatings. This generic group as a whole was between 45 and 61 percent more effective than the control specimen. Material Nos. 19, 20, and 16 received a low permeability rating and Nos. 24, 23, and 22 received a moderate rating. Masonry coatings all ranked in the lower half of the test group.

Appendix E of this report contains the results of the statistical analysis done on the data of the rapid chloride ion permeability test.

Conclusions

The following conclusions are made from the results of this, Phase II, of the chloride permeability testing.

1. The penetrating epoxies (especially those with the solids content of 50 percent) were effective against chloride permeability while comparing the uncoated control specimen.

2. The permeability resistance of the 100 percent solids epoxy was exceptional with negligible chloride intrusion.

3. The chemically-cured urethane was extremely effective against chloride permeation. The other, a moisture-cured urethane, was very ineffective.

4. The effectiveness of the silanes was found to be related to the solids content. The silane with only 20 percent solids content was less resistant to the penetration of chloride ions than those with the higher solids content.

5. The straight methyl methacrylate out-performed the other one with the silane primer by only 200 coulombs. However, both materials were over 75 more effective than the control.

6. The siloxane, silicone, and mixture of the two were fairly resistive against chloride permeability by achieving around 70 percent reduction of chlorides when compared to the control.

7. The masonry coatings, blend of silanes, and the poly-siloxane/fumed silica were ineffective materials against chloride permeability.

Appendix C
Water Absorption, Vapor Transmission, & Chloride Titration

Test Objectives

The objectives of this phase of the project were to evaluate the differences in water and chloride ion absorption for concrete coated with the 24 materials soaked in a 15 percent NaCl saltwater solution and the water vapor permeability characteristics of these coated specimens during an air drying period. The coated specimens were subjected to two different air drying environments. The first was a normal laboratory environment (72 degrees F and 50 % RH) and the second a much hotter and drier environment. Another objective of this phase was to examine the differences in results achieved, if any, from allowing the concrete to cure to different stages before applying the selected coatings (9 days, 19 days, and 28 days). This phase evaluated the following parameters:

1. Water absorption - vapor transmission characteristics of surface-coated concretes

2. Chloride ion penetration into surface-coated concretes

3. Influence of different air drying periods before applying the coatings.

Test Materials

Preliminary trial batches were made to determine the correct mix design. The concrete was designed to meet the requirements of the Indiana Department of Transportation specifications for Class A concrete (8). The test concrete was designed to have a w/c ratio no greater than 0.66, an air content between 5 and 8 percent, a ratio of fine aggregate to total aggregate between 35 and 45 percent (by weight), and a slump of approximately 3 in.

The significant properties of the concrete and its materials were as follows:

Portland cement	Type I
Air-entraining agent, ml	205
Cement content, lb	564
Fine aggregate, lb	1350
Coarse aggregate, lb	1850
Fine/Total aggregate, %	42.2
Water content, lb	312
Air content, %	6.8
W/C (% by weight)	55.3
Slump, in.	3.25
28 day strength, psi.	4240
Absorption of fines, %	1.56
Absorption of coarse, %	1.15

Sample Preparations

The molds for the 4 inch cubes were constructed of steel and were coated with a thin film of oil to allow for the easy removal of the concrete cube after an adequate curing period. Three sets of 25 cubes were cast in order to accommodate each of the three sets for testing.

The fresh concrete was placed inside the molds in three approximately equal layers. Each layer was compacted by rodding, using 25 strokes with a 3/8 in. diameter steel rod. The molds were then covered with a sheet of plastic to prevent excess drying on the surface.

The prepared concrete cubes were stored for 24 hours in a laboratory environment. At the end of the 24 hour period, the molds were opened and the samples were placed in lime-saturated water for the next four days. Soaking the cubes in the lime-saturated water helped to prevent calcium hydroxide leaching which breaks down the internal structure and ultimately reduces the strength of the concrete. All six sides of the cubes were lightly sandblasted after the moisture curing period at an age of 5 days to remove any oil that may have still been present on the surfaces and the cement skin which would normally wear off by weathering.

Test Procedures

The sealers/coatings were all applied at the rate of 100 sf/gal. The purpose behind this was to try and eliminate as many variables as possible from the testing in an effort to concentrate on the difference results obtained from the three separate tests. The amount of material for each cube was calculated using the weight of the material in lbs. per gallon, the surface area of the cube, and the 100 sf/gal coverage rate. These amounts were applied by brush. The second coat, if necessary, was applied after 24 hours. The cubes were then stored in a laboratory environment (73F and 20%RH) for seven days.

At the age of 7 days, the cubes were divided into three separate sets. The first set of 25 cubes were coated at an age of 9 days after an air drying period of 3 days after sandblasting. The second set of 25 cubes were coated at an age of 19 days after an air drying period of 13 days. The third set of 25 cubes were coated at an age of 28 days after an air drying period of 22 days. Each set had a control specimen to compare the coated cubes with. After the 7 days drying period for the coatings, the cubes were weighed and immersed in a 15 percent NaCl solution. The first set was immersed at the age of 17 days, the second - 26 days, and the third - 35 days.

Twelve cubes were placed in a plastic container with approximately six gallons of 15 percent NaCl solution. About an inch cover of the solution was maintained over the tops of the cubes. During the soaking period, the gain in the S.S.D. cube weight after 3,

6, 9, 12, 15, 18, and 21 days of soaking was determined to the nearest 0.001 lb. Immediately after each weighing, the cubes were returned to the solution. The salt solution was stirred periodically to eliminate settling. After 21 days of saltwater soaking, each set of cubes were removed from the water bath and moved to a climately controlled room (70F and around 65%RH). They were stored on steel racks and moved periodically to reduce the effect of variations in air circulation. During the following 24 day air drying period, the loss in weight at 3, 6, 9, 12, 15, 18, 21, and 24 days was determined by weighing to the nearest 0.001 lb. After the 24 air drying period, the cubes moved to another environmentally controlled room for 12 more days (100 degrees F and 20% RH). The loss in weight at 27, 30, 33, and 36 days was also determined by weighing to the nearest 0.001 lb.

Chloride Ion Content Procedure

Following the water absorption and vapor transmission testing, powder samples were taken from each of the 24 coated cubes and the untreated control specimen from all three sets. Two holes were drilled in each of the cubes, one on one side, the second on the opposite side, in order to extract the powder samples. Three powder samples were taken from both of the holes in each cube, giving us a total of six samples from each cube. Each hole was first drilled to a depth of 1/2 in. The first powder sample was taken at a depth of 1/2 in., the second at 1 in., and the third at 1-1/2 in. All six of the

1/2 in., the second at 1 in., and the third at 1-1/2 in. All six of the powder samples were tested for chloride content and the two values at the same depths were averaged together. The total chloride content was determined using an acid digestion potentiometric titration procedure. This testing was performed at the IDOH Materials and Testing Lab with the help of their personnel.

Discussion of Test Results

The individual weight change results at the conclusion of the soaking and drying tests for all three sets of 24 samples (plus each sets' untreated control specimen), are given in Tables C-9 through C-14 near the end of this Appendix. Also at end of this Appendix are the weight change results displayed graphically in Figures C-7 through C-31. Table C-1 shows the weight gain as a percentage of the original weight for all three set. The residual weight change after the drying period for all three sets is displayed in Table C-2. The results of all three of the water absorption (weight gain) test sets will be discussed first, followed by a discussion of each sets' final residual weight change. The last section will compare each samples' results across the three separate sets.

Weight Gain Results

Weight Gain for Set 1. The final weight gain data shown in Table C-1 can be separated into the following three groups:

Table C-1

Weight Gain After 21 Days in 15% NaCl Water Solution

Weight gain, % by wt.	Set #1 Test No.	Set #2 Test No.	Set #3 Test No.	Group No.
0.11		4		
0.15	4,12			
0.19	1	12	12	
0.22		25		
0.27			10	
0.29			25	
0.30			8	
0.34		1,10,11	11,14	
0.36	25	5,14		
0.38	14		7	
0.42	10		1,2	
0.45		8		
0.49	3	18	4,15,18	
0.53	8,11		9	1A
0.56	5			
0.57	2			
0.60		7		
0.63	20			
0.68	7	15		
0.72	13,15			
0.76	9	2,9		
0.79			5	
0.87			13	
0.90	22			
0.93		20		
0.94			3	
0.95			16	
0.97	16			
1.00		16		
1.06		3		
1.15		22		
1.21	18			
1.34		13	20,22	
1.50	23			
1.65		19		
1.67			24	
1.71			19	
1.77	6			2A
1.83		23		
1.84	19			
1.87	24			
1.91			23	
1.94		6		
1.96		24		
1.99			21	
2.05			6	
2.12	21			
2.16		21		
2.20			Control	
2.51		Control		
2.62	Control			

Group No.	Final Weight Gain, %	No. of Materials
1A	less than 1.0	18
2A	greater than 1.0; less than 2.62	6

The 18 samples in Group 1A were coated with all five of the epoxy formulations (Nos. 2 and 4 - 2 coats; Nos. 2, 3, and 25 - 1 coats), a urethane (No. 5 - 1 coat), all four of the silanes (Nos. 7, 8, 9, and 10 - 1 coat each), a silicone (No. 11 - 2 coats), two methyl methacrylates (Nos. 12 and 13 - 2 coats each), a siloxane (No. 14 - 1 coat), a siloxane/silicone mixture(No. 15 - 2 coats), two styrene/acrylic copolymers (No. 16 - 1 coat, No. 22 - 2 coats), a and polyester resin (No. 20 - 1 coat).

The six samples in Group 2A showed weight gains between 1.0 percent and 2.62 percent, which was the weight gained by the untreated control specimen. These six samples were coated with a urethane (No. 6 - 2 coats), a blend of silanes (No. 18 - 1 coat), a vinyl acrylic (No. 19 - 1 coat), an elastomeric acrylic (No. 23 - 2 coats), an acrylic resin (No. 24 - 2 coats), and a material with no specific generic type (No. 21 - 1 coat).

There were no samples that exhibited weight gains greater than the untreated control specimen.

Weight Gain for Set 2. The final weight gain data shown in Table C-1 can be separated into the following three groups:

Group No.	Final Weight Gain, %	No. of Materials
1A	less than 1.0	16
2A	greater than 1.0; less than 2.62	8

The 16 samples in Group 1A were coated with four epoxy formulations (Nos. 1 and 4 - 2 coats, Nos. 2 and 25 - 2 coats), a urethane (No. 5 - 1 coat), all of the silanes (Nos. 7, 8, 9, and 10 - 1 coat each), a silicone (No. 11 - 2 coats), a methyl methacrylate (No. 12 - 2 coats), a siloxane (No. 14 - 2 coats), a siloxane/silicone mixture (No. 15 - 2 coats), a styrene/acrylic copolymer (No. 16 - 1 coat), a blend of silanes (No. 19 - 1 coat), and a polyester resin (No. 20 - 1 coat).

The eight samples in Group 2A exhibited weight gains between 1.0 percent and 2.51 percent, which was the amount gained by the control specimen. These eight samples were coated with an epoxy (No. 3 - 1 coat), a urethane (No. 6 - 2 coats), a methyl methacrylate (No. 13 - 2 coats), a vinyl acrylic (No. 19 - 1 coat), a styrene/acrylic copolymer (No. 22 - 2 coats), an elastomeric acrylic (No. 23 - 2 coats), an acrylic resin (No. 24 - 2 coats), and a mixture with no specific generic type (No. 21 - 1 coat).

There were no samples in this set that demonstrated weight gains greater than the control specimen.

Weight Gain for Set 3. The final weight gain data shown in Table C-1 can be separated into the following three groups:

Group No.	Final Weight Gain, %	No. of Materials
1A	less than 1.0	17
2A	greater than 1.0; less than 2.20	7

The 17 samples in Group 1A were coated with all five of the epoxy formulations (Nos. 2 and 4 - 2 coats; Nos. 2, 3, and 25 - 2 coats), a urethane (No. 5 - 1 coat), all four of the silanes (Nos. 7, 8, 9, and 10 - 1 coat each), a silicone (No. 11 - 2 coats), both methyl methacrylates (Nos. 12 and 13 - 2 coats each), a siloxane (No. 14 - 1 coat), a siloxane/silicone mixture (No. 15 - 2 coats), a styrene/acrylic copolymer (No. 16 - 1 coat), and a blend of silanes (No. 18 - 1 coat).

The seven samples in Group 2A exhibited weight gains between 1.0 percent and 2.20 percent, which was the amount gained by the control specimen. These samples were coated with a urethane (No. 6 - 2 coats), a vinyl acrylic (No 19 - 1 coat), a polyester resin (No. 20 - 1 coat), a styrene/acrylic copolymer (No. 22 - 2 coats), an elastomeric acrylic (No. 23 - 2 coats), an acrylic resin (No. 24 - 2 coats), and a mixture with no specific generic type (No. 21 - 1 coat).

There were no samples in this set that demonstrated weight gains greater than the control specimen.

Final Residual Weight Change Results

Residual Weight Change for Set 1. The final residual weight change data shown in Table C-2 can also be separated into the following three groups:

Table C-2

Residual Weight Change After 24 Days in Air at 73 Degrees F and 50% RH, and 12 Days at 100 Degrees F and 27% RH

Residual wt. change %, by wt.	Set #1 Test No.	Set #2 Test No.	Set #3 Test No.	Group No.
-1.36	12			
-1.22			7	
-1.21	14		11,12	
-1.18		11	14	
-1.13			15	1B
-1.10	10		8	
-1.09		12		
-1.07	8	14		
-1.06	2,11			
-1.05	7			
-1.03			2,9	
-1.02			10	
-0.99	9		18	
-0.98		8		
-0.95	15			
-0.94	3			
-0.92	20			
-0.91		10		
-0.87	13	18		
-0.80		15		
-0.79		2,9		
-0.78	18	7		
-0.77			20	
-0.76	16		13	
-0.74		20		2B
-0.70			16	
-0.67	22			
-0.66		16		
-0.65	4			
-0.63			22	
-0.60	1			
-0.59		22		
-0.54		13		
-0.53			1	
-0.45	6		3	
-0.41		4	21	
-0.38	21	3		
-0.36			19,24	
-0.34		1	1,Control	
-0.30	5	6,21		
-0.26	23			
-0.23		Control		
-0.22	24			
-0.18	19			
-0.15		19		3B3
-0.08			5,23	
-0.04		23,24		3B2
0.00	Control	5	6	
0.04		25		
0.07	25			3B1
0.15			25	

Group No.	Residual Weight Change, %	No. of Materials
1B	-1.36 to -1.00	7
2B	-0.99 to 0.00	16
3B	0.01 to 0.07	1

The seven materials in Group 1B all lost more weight by vapor transmission during the drying period than they gained during the soaking period. All seven of these samples were also from Group 1A which gained the least amount of weight during soaking (Nos. 12, 14, 10, 8, 11, 2, and 7).

The 16 samples in Group 2B all lost more weight during the drying period than they gained during the soaking period, but they performed better than the untreated control specimen, which had a residual weight change of 0.00 percent (Nos. 9, 15, 3, 20, 13, 18, 16, 22, 4, 1, 6, 21, 5, 23, 24, and 19).

There was only one sample (No. 25) in Group 3B1 that gained more weight during the soaking period than it lost during drying.

Residual Weight Change for Set 2. The final residual weight change data shown in Table C-2 can also be separated into the following three groups:

Group No.	Residual Weight Change, %	No. of Materials
1B	-1.18 to -1.00	3
2B	-0.99 to -0.23	17
3B1	-0.22 to 0.04	4

The three materials in Group 1B all lost more weight by vapor transmission during the drying period than they gained during the soaking period. All three of these samples were also from Group 1A which gained the least amount of weight during soaking (Nos. 12, 14, and 11).

The 17 samples in Group 2B all lost more weight during the drying period than they gained during the soaking period, but they performed better than the untreated control specimen, which had a residual weight change of -0.23 percent (Nos. 8, 10, 18, 5, 15, 2, 9, 7, 20, 16, 22, 13, 4, 3, 1, 6, and 21).

There were four samples (No. 19, 23, 24, and 25) in Group 3B2. The first three samples lost more weight during the drying period than they gained during soaking. The last sample (No. 25) was the only one to gain more weight during the soaking period than it lost during drying.

Residual Weight Change for Set 3. The final residual weight change data shown in Table C-2 can also be separated into the following three groups:

Group No.	Residual Weight Change, %	No. of Materials
1B	-1.21 to -1.00	9
2B	-0.99 to -0.34	11
3B1	-0.33 to 0.15	4

The nine materials in Group 1B all lost more weight by vapor

transmission during the drying period than they gained during the soaking period. All nine of these samples were also from Group 1A which gained the least amount of weight during soaking (Nos. 7, 11, 12, 14, 15, 8, 2, 9, and 10).

The 11 samples in Group 2B, except sample No. 4 that equal the control specimen, all lost more weight during the drying period than they gained during the soaking period, but they performed better than the untreated control specimen which had a residual weight change of -0.34 percent (Nos. 2, 9, 10, 18, 20, 13, 16, 22, 1, 2, 21, 19, 24, and 4).

There were four samples (No. 5, 23, 6, and 25) in Group 3B3. The first two samples lost more weight during the drying period than they gained during soaking. The third sample's residual weight change was 0.00 percent, the last sample (No. 25) was the only one to gain more weight during the soaking period than it lost during drying.

The same test results are presented in Table C-3, ranked according to their weight loss as a percentage of weight gain. Groups are separated here into those that lost four or more times what they gained (Group 1C), those that lost two to four times what they gained (Group 2C), those that lost one to two times what they gained (Group 3C), and those that gained more than they lost (Group 4C).

Table C-3

Weight Loss After All Drying as a Percentage
of Weight Gain Caused by Soaking

SET Weight loss, %	#1 Test No.	SET Weight loss, %	#2 Test No.	SET Weight loss, %	#3 Test No.	Group No.
1000.0	12					
				740.0	12	
		680.0	12			
525.0	4					
470.0	14			485.7	10	1C
		466.7	4	462.5	8	
				455.6	11	
		444.4	11	444.4	14	
420.0	1			420.0	7	
		380.0	14			
363.6	10	366.7	10	345.5	2	
				330.8	15	
300.0	8,11	316.7	8	300.0	18	
292.0	3			292.9	9	
286.7	2	284.6	18			
255.6	7					2C
247.1	20					
231.6	15	231.3	7			
230.0	9	227.8	15	227.3	1	
221.1	13	205.0	2,9			
176.9	16	180.0	1,20	187.0	13	
175.0	22			173.1	16	
				169.2	4	
162.5	18	166.7	16	167.7	20	
153.3	5	151.6	22	148.0	3	
				147.2	22	
		140.0	13			
		135.7	3			
125.5	6			121.7	24	
117.9	21	115.7	6	121.3	19	3C
				120.8	21	
114.0	23	114.0	21	115.5	Control	
111.8	24					
110.0	19	109.1	Control			
		108.9	19			
				104.8	5	
		102.0	23	103.8	23	
		101.9	24			
		100.0	5	100.0	6	
80.0	25	83.3	25			
				50.0	25	4C
0.0	Control					

Individual Water Absorption and Vapor Transmission Characteristics

In the following subsections, the different materials are reviewed with regard to the water absorption characteristics, vapor transmission characteristics, chloride permeability characteristics, and the effect that coating at differing stages of the curing process has upon these characteristics.

Epoxies. The weight gain characteristics of all but one of the five of the epoxy formulations are found in Group 1A of Table C-1.

The weight gain characteristics of sample No. 1 were relatively high for all three sets, but they dropped slightly in each successive set. The rankings decreased from third, to tied for fourth with three others, finally to tied for eighth. Its vapor transmission characteristics were better than the control specimen's for all three sets, but were all in Group 2B. This sample lost more weight in the first set followed by the third set and then the second set. It lost four times what it gained in set 1 and only around two times in sets 2 and 3. This sample had a solids content of 50 percent and retained a shiny appearance after treatment.

The weight gain characteristics of sample No. 2 were varied over each of the sets. It was eleventh and in the middle of Group 1A for the first set, thirteenth and lower in the second set, and tied for seventh and in the top third of Group 1A in the last set. The vapor transmission characteristics dropped a significant amount from the first set (Group 1B) to the second set (Group 2B) and returned to nearly the same value as the first set in the final set. It required

only one coat and had a 20 percent solids content.

Sample No. 3's water absorption results varied quite a bit between the different sets. It was seventh and in the middle of Group 1A in the first set, seventeenth and in the top of Group 2A in the second set, and sixteenth and in the bottom of Group 1A in the final set. The vapor transmission characteristics nearly followed the same pattern. They went from tenth, down to seventeenth, and increased slightly to sixteenth. It had a ratio of weight loss to weight gain of almost three for the first set and half that for the other two sets. This material had a solids content of 50 percent and required only one coat.

Sample No. 4 performed extremely well in terms of the water absorption test. Its results were as follows: tied for first in set 1, first in set 2, dropped to tied for tenth in the middle of Group 1A in the third set. In terms of the vapor transmission characteristics, sample No. 4's values decreased slightly from the first set to the third set, starting in the middle of Group 2B and finishing at the border of Groups 2B and 3B3. Sample No. 4 had the second highest weight loss to weight gain ratio in both the first and second sets at around five times more loss than gain, while it dropped off to under two times in the third set. It required two coats and had a solids content of 50 percent.

Sample No. 25 was one of the most effective materials against absorbing water. It was fourth in the first set and second in the other two sets, finishing in the top third of Group 1A in all three sets. This was the only material that in all three sets, gained more weight

than it lost. It had a solids content of 100 percent and required only one coat.

Urethanes. The material labeled No. 5 can be found in the top half of Group 1A in all three sets in terms of its water absorption characteristics. It's water absorption characteristics were better in the second set, while the residual weight change results indicated that the first set was slightly better than the others. It required only one coat and had a solids content of 55 percent.

Sample No. 6 is a moisture-cured urethane, required two coats, and had a solids content of 30 percent. The results were consistently located in the lower groups of all three sets for both the water absorption and vapor transmission tests. Coating the cube earlier in the curing period increased the performance of this product. This sample's performance was slightly above that of the control specimen.

Silanes. Samples labeled No. 7 through No. 10 are all classified as penetrants requiring only one coat each. They performed very well, all finishing in Group 1A in terms of weight gain. Of these four silanes, sample No. 10 was the most effective in the water absorption test, followed by No. 8, No. 7, and finally No. 9. The weight gain values increased slightly with each successive set and the silanes remained in the order stated above in each set.

In set 1, sample No. 10 lead all of the silanes in terms of residual weight change, followed closely by No. 8, No. 7, and finally No. 9. All four of the silanes were in Group 1B. In set 2, all of the weight change values decreased slightly and had the following

ranking: No. 8, No. 10, No. 9, and then No. 7. Each of these values dropped to Group 2B as shown in Table C-2. In set 3, the weight change characteristics of all four of the silanes increased to above set 1 values, except for sample No. 10. In fact, sample No. 7 was first overall, while No. 8 finished sixth, No. 9 was tied for eighth, and No. 10 was ninth. Each of the silanes were in Group 1B.

The ratio of the weight loss to the weight gain values for all of the silanes were quite high in all three sets. In set 1, sample No. 10's ratio was over 3.5, No. 8 had a ratio of 3.0, No. 7's ratio was around 2.5, and No. 9's ratio was 2.3. The order of the silanes remained the same in set 2 and 3 as they were in set 1. The values for set 2 were almost identical to that of set 1. In set 3, however, the weight loss to weight gain ratios increased for each of the silanes.

Silicone. This material, labeled No. 11, is classified as a penetrant and required two coats. The solids content of this material was 5 percent. This material performed very effectively in the water absorption and vapor transmission tests. It was consistently in the upper groups of Tables C-1 through C-3. Set 3's results were better than the other two followed by Set 2 and then Set 1, indicating that this material performs more effectively when coated at a latter stage of the curing period.

Methyl Methacrylate. Sample No. 12 consisted of a two coat application process. The first coat was an aklyl-alkoxy silane, while the top coat was a methyl methacrylate polymeric coating. This material was the most effective coating system in this phase of testing of all three of the sets. It lost ten times the weight that it

gained in the first set, lost 6.8 times what it gained in the second set, and lost 7.4 times what it gained in the third set.

The other methyl methacrylate, labeled No. 13, had a 30 percent solids content and required two coats. This material was consistently in the middle of the pack in terms of its water absorption and vapor transmission results for all three sets. It performed slightly better in the first set followed by the third set, and then the second set.

Siloxane. This material, labeled No. 14, was quite effective at resisting moisture penetration with values of less than 0.40 percent weight gain. It's residual weight change results indicated that it allowed the concrete to breath fairly easily. The results indicated that this material was quite consistent with the first set's results slightly higher than the third set's, followed by the second set.

Siloxane/Silicone. Sample No. 15, a siloxane/silicone mixture, is classified as a penetrant that required two coats and had a solids content of 10 percent. The weight gain characteristics of this material were average for the first two sets, but improved a bit in the third set. The vapor transmission characteristics for the first and second set were also average, while the third set's results were extremely high (fourth overall). The ratio of weight loss to weight gain for the first and second set was around 2.3, while for the third set its ratio climbed to over 3.3 (in the upper half of Group 2C).

Blend of Silanes. Material No. 18 is a blend of natural oils, resins, silanes, siloxanes, stearates, and aluminum compounds in blended solvents and is classified as a penetrant. It had a solids

content of 30 percent and required only one coat. The water absorption characteristics of this material improved greatly from the first set (19th overall) to the second and third set (10th overall in both). Its vapor transmission characteristics followed the same trend as mentioned in the previous statement. This material's overall effectiveness improved from the first set to the last.

Poly-Siloxane/Fumed Silica. Sample No. 21 is a combination of a poly-siloxane/hydrophobic-fumed silica. This penetrant required one coat and had a solids content of 7 percent. This material was fairly consistent across all three sets in both tests. Its final results were slightly above that of the control specimen for all three sets.

Masonry Coatings.

Styrene/Acrylic Copolymer. There were two materials that were of this generic type. Sample No. 16 had a solids content of 75 percent and required two coats. Sample No. 22 required two coats and had a 61 percent solids content. Both of these materials had about the same effectiveness in terms of water absorption and vapor transmission. They both performed better than the control specimen, but ranked in the lower half of each test in all three sets. The results for material No. 16 were very consistent across each set, while material No. 22's results dropped off from the first set to the last set. Overall, Sample No. 16 was slightly more effective than Sample No. 22.

Vinyl Acrylic. Sample No. 19 is a type of masonry coating which had a solids content of 58 percent and required one coat. This material was consistently near the bottom of the rankings for both

tests and for each set. It did, however, perform slightly better in the final set than either of the other sets. Its effectiveness overall was just above that of the control specimen.

Polyester Resin. Material No. 20 is considered a sealer with a solids content of 60 percent and required one coat. The weight gain characteristics of this sample were average when compared to all of the samples, while they doubled from the first set to the last. The ratio of weight loss to weight gain was around 2.5 in the first set, 1.8 in the second set, and around 1.7 in the third set. These results conflicted with the manufacturer's recommendations in terms of the curing period before coating.

Resin-base Masonry Coating. There were two materials of this generic type. Sample No. 23 is an elastomeric acrylic resin-based masonry coating and required two coats. The other one, Sample No. 24, is an acrylic resin-based masonry coating and also required two coats. Both of these materials' performances were right around that of the control specimen for each set of both tests. They were two of the most ineffective samples of all of the products tested. Sample No. 23's values decreased with each successive set, while Sample No. 24 performed better in the final set.

Chloride Titration Results

The overall average percent chloride content ranging between a depth of 1/2 in. and 1-1/2 in. for all three sets of 24 samples and

their untreated control specimens can be found in Table C-4 and are depicted graphically in Figures C-1 through C-3. Tables C-15 through C-17 give the average chloride content ranging from 1/2 in. to 1-1/2 in. of each material and their respective rank. All of the individual chloride titration data, Tables C-18 through C-20, have also been provided. Tables C-15 through C-20 can be found near the end of this Appendix. The following subsections discuss the chloride content data found in Table C-4 by each set. The chloride content values shown in Table C-4 are compared in Table C-5 for all three sets.

Chloride Content For Set 1. The chloride content data shown in Table C-5 can be separated into the following three groups:

Group No.	Average Chloride Content, %	No. of Materials
1D	0.0000 to 0.0500	2
2D	0.0501 to 0.2710	20
3D1	0.2711 to 0.2837	2

Only two materials had values less than 0.0500 percent chloride by weight. One material was the 100 percent solids epoxy and the other was the methyl methacrylate with the silane primer.

The 20 materials in the second group, labeled 2D, had chloride content values greater than 0.0500 percent but less than 0.2175 percent, the amount absorbed by the untreated control specimen. They were four epoxies (Nos. 1-4), both urethanes (Nos. 5 and 6), all

Table C-4

Chloride Titration Results - Water Abs./Vapor Trans.

Sample Number	Generic Type (% solids)	OVERALL AVERAGE CHLORIDE CONTENT Set 1 Percent	Set 2 Percent	Set 3 Percent
1	Epoxy (40)	0.0597	0.0522	0.0598
2	Epoxy (20)	0.1125	0.0760	0.0545
3	Epoxy (50)	0.1518	0.1157	0.1943
4	Epoxy (50)	0.0723	0.0370	0.0797
5	Urethane (55)	0.0658	0.0275	0.0967
6	Urethane (30)	0.2138	0.1730	0.3070
7	Silane (40)	0.1045	0.0418	0.1005
8	Silane (<20)	0.0617	0.0428	0.0392
9	Silane (20)	0.0937	0.1225	0.1567
10	Silane (40)	0.0997	0.0570	0.0488
11	Silicone (5)	0.0540	0.0388	0.0453
12	Methyl Methacrylic (20)	0.0437	0.0380	0.0328
13	Methyl Methacrylic (30)	0.0907	0.1318	0.0698
14	Siloxane (20)	0.0985	0.0847	0.0385
15	Siloxane/Silicone (10)	0.0930	0.1068	0.0402
16	Styrene Acrylic Copolymer (61)	0.0920	0.0725	0.0495
18	Blend of Silanes (30)	0.1952	0.0747	0.0618
19	Vinyl Acrylic (58)	0.2568	0.2037	0.1602
20	Polyester Resin (60)	0.1003	0.0948	0.0965
21	Poly-Siloxane/Silica (7)	0.2810	0.2405	0.2020
22	Styrene Acrylic Copolymer (75)	0.1015	0.0992	0.1127
23	Elastomeric Acrylic	0.2213	0.1603	0.2183
24	Acrylic Resin	0.2837	0.2232	0.1973
25	Epoxy (100)	0.0367	0.0268	0.0665
Control	-----	0.2710	0.2175	0.2632

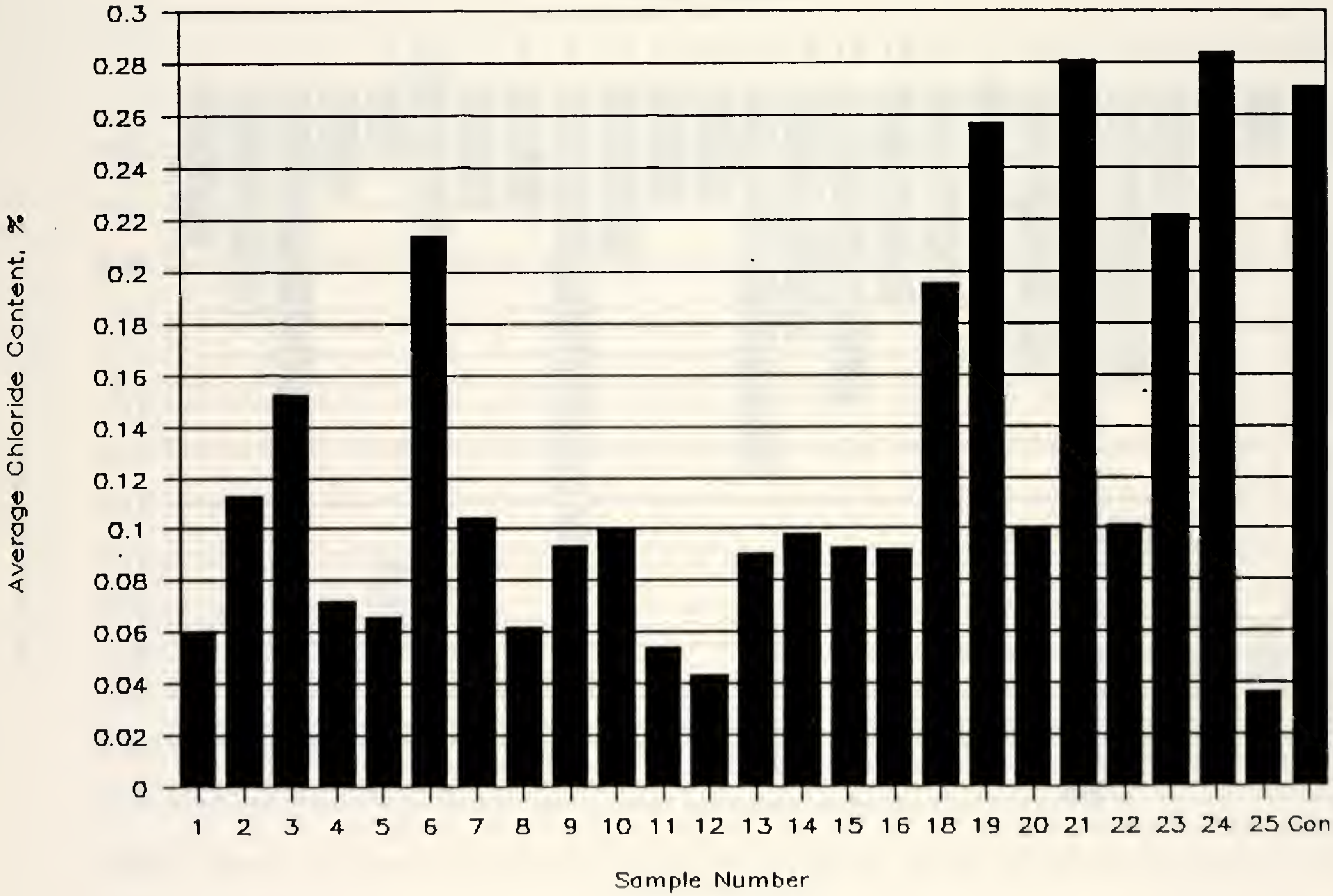

Figure C-1

Water Abs./Vapor Trans., Average Chloride Content - Set 1

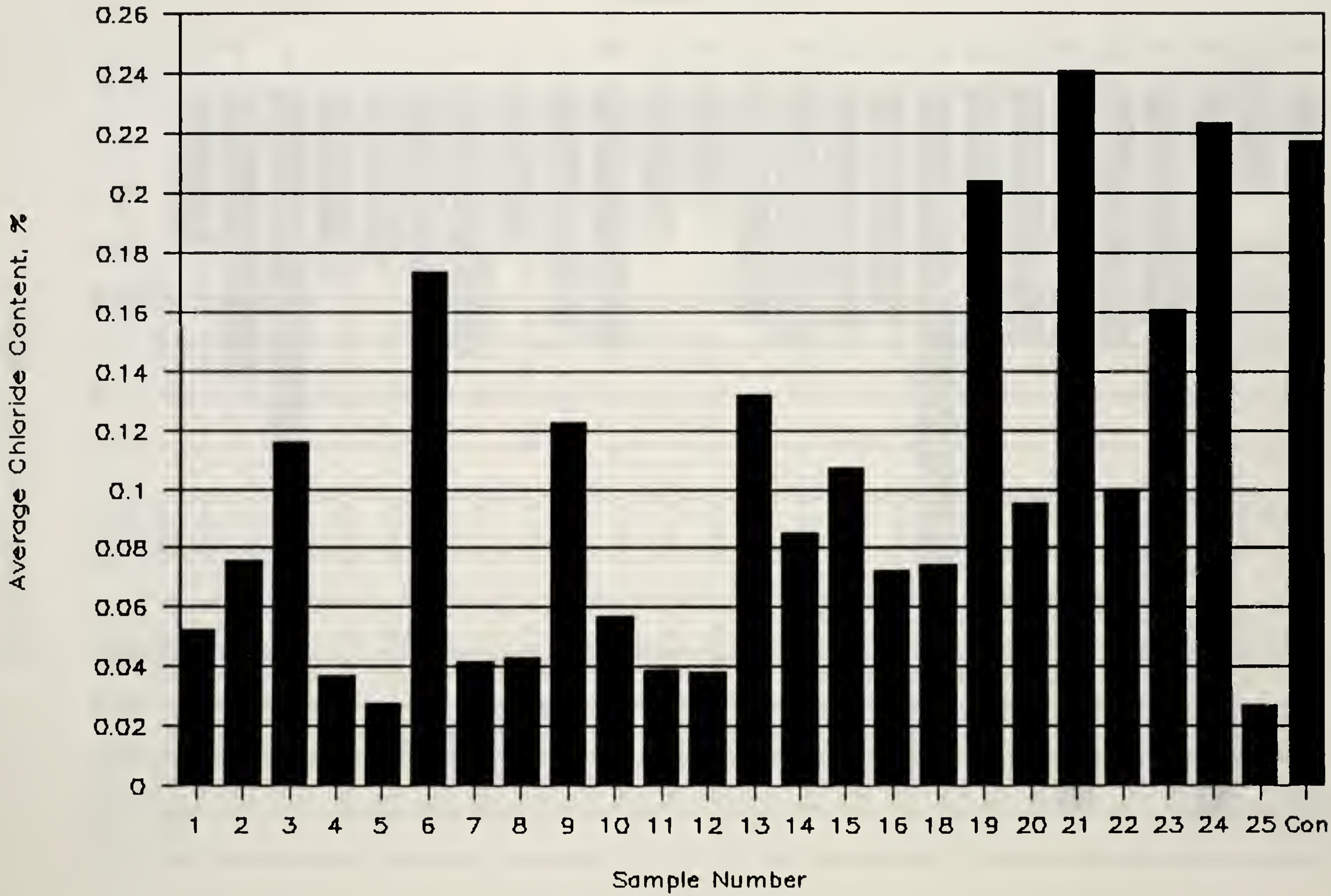

Figure C-2

Water Abs./Vapor Trans., Average Chloride Content - Set 2

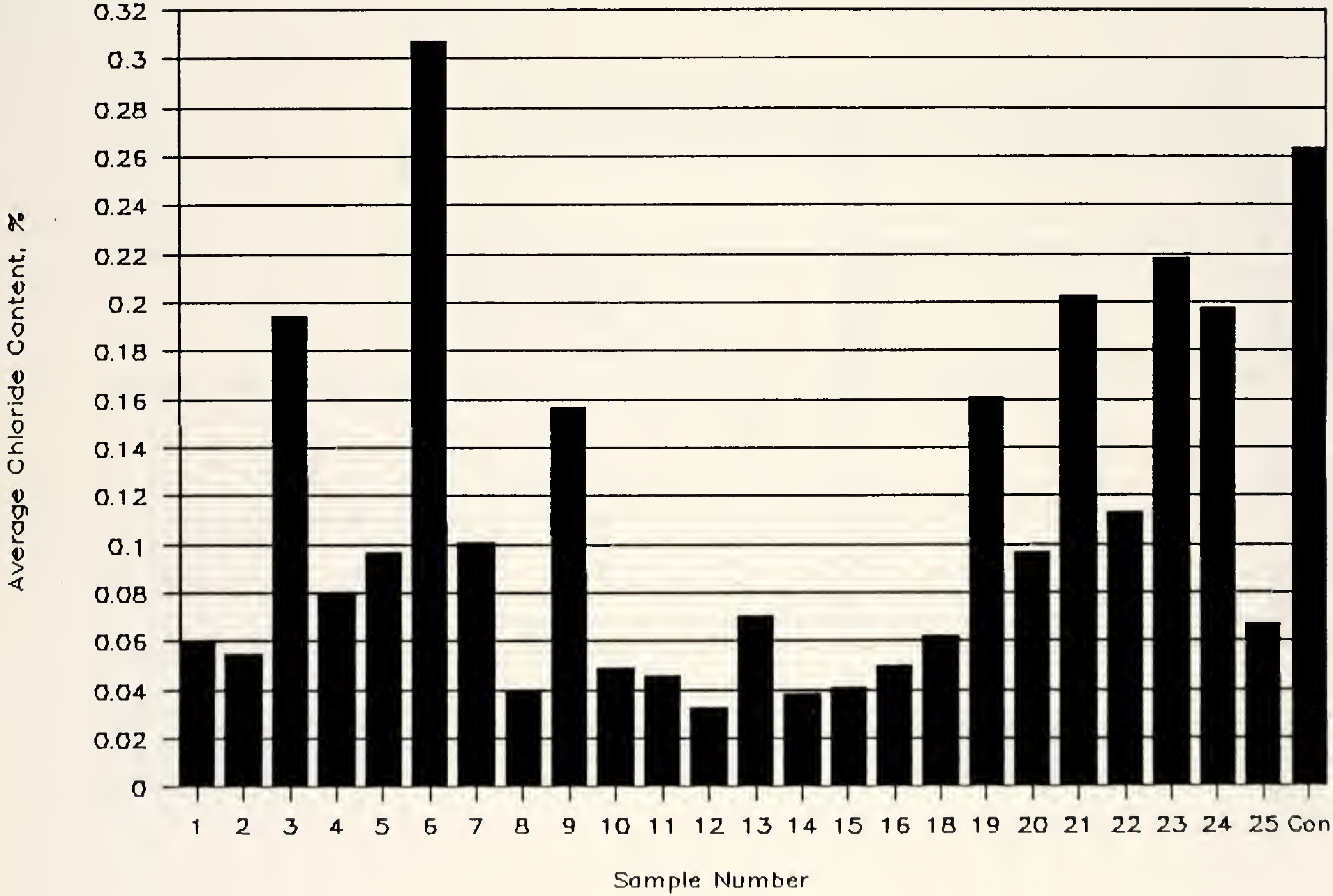

Figure C-3

Water Abs./Vapor Trans., Average Chloride Content - Set 3

Table C-5

Overall Average Chloride Content Comparison Between Sets

Overall Average Chloride Content	Set 1 Sample #	Set 2 Sample #	Set 3 Sample #	Group Number
0.0000				
0.0236		25		
0.0275		5		
0.0328			12	
0.0367	25			
0.0370		4		
0.0380		12		
0.0385			14	
0.0388		11		1D
0.0392			8	
0.0402			15	
0.0418		7		
0.0428		8		
0.0437	12			
0.0453			11	
0.0488			10	
0.0495			16	
0.0522		1		
0.0540	11			
0.0545			2	
0.0570		10		
0.0597	1			
0.0598			1	
0.0617	8			
0.0618			18	
0.0658	5			
0.0665			25	
0.0698			13	
0.0723	4			
0.0725		16		
0.0747		18		
0.0760		2		
0.7970			4	
0.0847		14		
0.0907	13			2D
0.0920	16			
0.0930	15			
0.0937	9			
0.0948		20		
0.0965			20	
0.0967			5	
0.0985	14			
0.0992		22		
0.0997	10			
0.1003	20			
0.1005			7	
0.1015	22			

Table C-5, continued

Overall Average Chloride Content	Set 1 Sample #	Set 2 Sample #	Set 3 Sample #	Group Number
0.1045	7			
0.1068		15		
0.1125	2			
0.1127			22	
0.1157		3		
0.1225		9		
0.1318		13		
0.1518	3			
0.1567			9	
0.1602			19	
0.1603		23		
0.1730		6		2D
0.1943			3	
0.1952	18			
0.1973			24	
0.2020			21	
0.2037		19		
0.2138	6			—
0.2175		Control		
0.2183			23	
0.2213	23			
0.2232		24		
0.2405		21		3D2
0.2568	19			
0.2632			Control	—
0.2710	Control			—
0.2810	21			3D3
0.2837	24			3D1
0.3070			6	

four silanes (Nos. 7-10), a silicone (No. 11), a methyl methacrylate (No. 13), a siloxane (No. 14), a siloxane/silicone mixture (No. 15), five masonry coatings (Nos. 16, 19, 20, 22, and 23), and a blend of silanes (No. 18).

The two samples in Group 3D1 had higher chloride contents than the control specimen. One was an acrylic resin based masonry coating (No. 24) and the other material was the poly-siloxane/fumed silica (No. 21).

Chloride Content For Set 2. The chloride content data shown in Table C-5 can be separated into the following three groups:

Group No.	Average Chloride Content, %	No. of Materials
1D	0.0000 to 0.0500	7
2D	0.0501 to 0.2175	15
3D2	0.2176 to 0.2405	2

The seven materials in group 1D had chloride content values less than 0.0500 percent by weight. These included two epoxies (Nos. 25 and 4), a urethane (No. 5), two silanes (Nos. 7 and 8), a silicone (No. 11), and a methyl methacrylate (No. 12).

The 15 materials in the second group, labeled 2D, had chloride content values greater than 0.0500 percent but less than the control specimen, at 0.2175 percent. They were three epoxies (Nos. 1, 2, and 3); a moisture-cured urethane (No. 6); two silanes (Nos. 9 and 10); a methyl methacrylate (No. 13); a siloxane (No. 14); a

siloxane/silicone mixture (No. 15); five masonry coatings (Nos. 16, 19, 20, 22, and 23); and a blend of silanes (No.18).

The two samples in group 3D2 had higher chloride contents than the control specimen. They were the same two in group 3D1; an acrylic resin based masonry coating (No. 24) and the poly-siloxane/fumed silica (No. 21).

Chloride Content For Set 3. The chloride content data shown in Table C-5 can be separated into the following three groups:

Group No.	Average Chloride Content, %	No. of Materials
1D	0.0000 to 0.0500	7
2D	0.0501 to 0.2632	16
3D3	0.2633 to 0.3070	1

The seven materials in group 1D had chloride content values less than 0.0500 percent by weight. They were two silanes (Nos. 8 and 10), silicone (No. 11), a methyl methacrylate (No. 12), a siloxane (No. 14), a siloxane/silicone mixture (No. 15), and a styrene acrylic copolymer based masonry coating (No. 16).

The 16 materials in the second group, labeled 2D, had chloride content values greater than 0.0500 percent but less than the control specimen, at 0.2632 percent. These included all five epoxies (Nos. 1, 2, 3, 4, and 25); a urethane (No. 5); two silanes (Nos. 7 and 9); a methyl methacrylate (No. 13); five masonry coatings (Nos. 19, 20, 22, 23, and 24); a blend of silanes (No. 18); and the poly-

siloxane/fumed silica (No. 21).

There was only one material in group 3D3 which had a higher chloride content than the untreated control specimen. This was the moisture-cured urethane (No. 6).

Values for chloride content and weight gain characteristics for all of the materials in each set are summarized in Tables C-6 through C-8 and displayed graphically in Figures C-4 through C-6. Also shown in Tables C-6 through C-8 are the percent reduction of chloride content and weight gain and their respective ranks when compared to the untreated control specimens.

Potential Sources of Errors

- All six sides of the cubes were sandblasted and there was no way to determine whether all six sides of all 75 cubes were sandblasted to the same degree. It was assumed that they all received the same amount of sandblasting.

- When the cubes were soaking in the saltwater solution, the solution had to be stirred everyday, but this still did not stop the salt from settling on the bottom of the container. Therefore there was a higher concentration of chlorides on the bottom of the container. This was partially combatted by rotating the cubes periodically.

- It was impossible to completely dry the surfaces of the cubes before weighing them each time. There may have been slightly varied results due to this problem.

Table C-6

Chloride Contents & Weight Change Results - Set 1

Test Number	Generic Type (% solids)	CHLORIDE CONTENT % by Weight	Percent Reduction	WEIGHT GAIN % by Weight	Percent Reduction	Residual Wt. Change % by wt.	Weight Loss, % by weight	Weight Loss Weight Gain Ratio, %
1	Epoxy (50)	0.0597	77.97	0.19	92.75	-0.60	0.79	420.0
2	Epoxy (20)	0.1113	58.49	0.57	78.24	-1.06	1.63	286.7
3	Epoxy (50)	0.1518	43.99	0.49	81.30	-0.94	1.43	292.0
4	Epoxy (50)	0.0723	73.32	0.15	94.27	-0.65	0.80	525.0
5	Urethane (55)	0.0658	75.72	0.56	78.63	-0.30	0.86	153.3
6	Urethane (30)	0.2138	21.11	1.77	32.44	-0.45	2.22	125.3
7	Silane (40)	0.1045	61.44	0.68	74.05	-1.05	1.73	255.6
8	Silane (<20)	0.0617	77.23	0.53	79.77	-1.07	1.60	300.0
9	Silane (20)	0.0937	65.42	0.76	70.99	-0.99	1.75	230.0
10	Silane (40)	0.0997	62.73	0.42	83.97	-1.10	1.52	363.6
11	Silicone (5)	0.0540	80.07	0.53	79.77	-1.05	1.58	300.0
12	Methyl Methacrylate (20)	0.0437	83.87	0.15	94.27	-1.36	1.51	1000.0
13	Methyl Methacrylate (30)	0.0907	66.53	0.72	72.52	-0.87	1.59	221.1
14	Siloxane (20)	0.0985	63.65	0.38	85.80	-1.21	1.59	470.0
15	Siloxane/Silicone (10)	0.0930	65.68	0.72	72.52	-0.95	1.67	231.6
16	Styrene/Acrylic Co. (75)	0.0920	66.05	0.97	62.98	-0.76	1.73	176.9
18	Blend of Silanes (30)	0.1952	27.97	1.21	53.82	-0.78	1.99	162.5
19	Vinyl Acrylic (58)	0.2568	5.24	1.84	29.77	-0.18	2.02	110.0
20	Polyester Resin (60)	0.1003	62.73	0.63	75.95	-0.92	1.55	247.1
21	Poly-Siloxane/Silica (7)	0.2810	-3.69	2.12	19.08	-0.38	2.50	117.9
22	Styrene/Acrylic Co. (61)	0.1015	62.55	0.90	65.65	-0.67	1.57	175.0
23	Elastomeric Acrylic	0.2213	18.34	1.50	42.75	-0.26	1.76	114.0
24	Acrylic Resin	0.2837	-4.69	1.87	28.63	-0.22	2.09	111.8
25	Epoxy (100)	0.0367	86.46	0.36	86.26	0.07	0.29	80.0
Control	-----	0.2710	0.00	2.62	0.00	0.00	2.62	0.0

Table C-7

Chloride Contents & Weight Change Results - Set 2

Test	Generic	CHLORIDE CONTENT		WEIGHT GAIN		Residual	Weight	Weight Loss
Number	Type (% solids)	% by Weight	Percent Reduction	% by Weight	Percent Reduction	Wt. Change % by wt.	Loss % by wt.	Weight Gain Ratio, %
1	Epoxy (50)	0.0522	76.00	0.34	86.45	-0.34	0.68	180.0
2	Epoxy (20)	0.0760	65.06	0.76	69.72	-0.80	1.56	205.0
3	Epoxy (50)	0.1157	46.80	1.06	57.77	-0.38	1.44	135.7
4	Epoxy (50)	0.0370	82.99	0.11	95.62	-0.41	0.52	466.7
5	Urethane (55)	0.0275	87.36	0.36	85.66	0.00	0.36	100.0
6	Urethane (30)	0.1730	20.46	1.94	22.71	-0.30	2.24	115.7
7	Silane (40)	0.0418	80.78	0.60	76.10	-0.79	1.39	231.3
8	Silane (<20)	0.0428	80.32	0.45	82.07	-0.98	1.43	316.7
9	Silane (20)	0.1225	43.68	0.76	69.72	-0.80	1.56	205.0
10	Silane (40)	0.0570	73.79	0.34	86.45	-0.92	1.26	366.7
11	Silicone (5)	0.0388	82.16	0.34	86.45	-1.18	1.52	444.4
12	Methyl Methacrylate (20)	0.0380	82.53	0.19	92.43	-1.09	1.28	680.0
13	Methyl Methacrylate (30)	0.1318	39.40	1.34	46.61	-0.54	1.58	140.0
14	Siloxane (20)	0.0847	61.06	0.36	85.66	-1.07	1.43	380.0
15	Siloxane/Silicone (10)	0.1068	50.90	0.68	72.91	-0.87	1.55	227.8
16	Styrene/Acrylic Co. (75)	0.0725	66.67	1.00	60.16	-0.66	1.66	166.7
18	Blend of Silanes (30)	0.0747	65.66	0.49	80.48	-0.91	1.40	284.6
19	Vinyl Acrylic (58)	0.2037	63.34	1.65	34.26	-0.15	1.80	108.9
20	Polyester Resin (60)	0.0948	56.41	0.93	62.95	-0.74	1.67	180.0
21	Poly-Siloxane/Silica (7)	0.2405	-10.57	2.16	13.94	-0.30	2.46	114.0
22	Styrene/Acrylic Co. (61)	0.0992	54.39	1.15	54.18	-0.59	1.74	151.6
23	Elastomeric Acrylic	0.1603	26.30	1.83	27.09	-0.04	1.87	102.0
24	Acrylic Resin	0.2232	-2.62	1.96	21.91	-0.04	2.00	101.9
25	Epoxy (100)	0.0268	87.68	0.22	91.24	0.04	0.18	83.3
Control	-----	0.2175	0.00	2.51	0.00	-0.23	2.74	109.1

Table C-8

Chloride Contents & Weight Change Results - Set 3

Test Number	Generic Type (% solids)	CHLORIDE CONTENT % by Weight	CHLORIDE CONTENT Percent Reduction	WEIGHT GAIN % by Weight	WEIGHT GAIN Percent Reduction	Residual Wt. Change % by wt.	Weight Loss % by wt.	Weight Loss Weight Gain Ratio, %
1	Epoxy (50)	0.0598	77.28	0.42	80.91	-0.53	0.95	227.3
2	Epoxy (20)	0.0545	79.29	0.42	80.91	-1.03	1.45	345.5
3	Epoxy (50)	0.1943	34.27	0.94	57.27	-0.45	1.39	148.0
4	Epoxy (50)	0.0797	69.72	0.49	77.73	-0.34	0.83	169.2
5	Urethane (55)	0.0967	63.26	0.79	64.09	-0.08	0.87	104.8
6	Urethane (30)	0.3070	-16.64	2.05	6.82	0.00	2.05	100.0
7	Silane (40)	0.1005	61.82	0.38	82.73	-1.22	1.60	420.0
8	Silane (<20)	0.0392	85.11	0.30	86.36	-1.10	1.40	462.5
9	Silane (20)	0.1567	40.46	0.53	75.91	-1.03	1.56	292.9
10	Silane (40)	0.0488	81.46	0.27	87.73	-1.02	1.29	485.7
11	Silicone (5)	0.0453	82.79	0.34	84.55	-1.21	1.55	455.6
12	Methyl Methacrylate (20)	0.0328	87.54	0.19	91.36	-1.21	1.40	740.0
13	Methyl Methacrylate (30)	0.0698	73.48	0.87	60.45	-0.76	1.63	187.0
14	Siloxane (20)	0.0385	85.37	0.34	84.55	-1.18	1.52	444.4
15	Siloxane/Silicone (10)	0.0402	84.73	0.49	77.73	-1.13	1.62	330.8
16	Styrene/Acrylic Co. (75)	0.0495	81.19	0.95	56.82	-0.70	1.65	173.1
18	Blend of Silanes (30)	0.0618	76.52	0.49	77.73	-0.99	1.48	300.0
19	Vinyl Acrylic (58)	0.1602	39.13	1.71	22.27	-0.36	2.07	121.3
20	Polyester Resin (60)	0.0965	63.34	1.34	39.09	-0.77	2.11	167.7
21	Poly-Siloxane/Silica (7)	0.2020	23.25	1.99	9.55	-0.41	2.40	120.8
22	Styrene/Acrylic Co. (61)	0.1127	57.18	1.34	39.09	-0.63	1.97	147.2
23	Elastomeric Acrylic	0.2183	17.06	1.91	13.18	-0.08	1.99	103.8
24	Acrylic Resin	0.1973	25.04	1.67	24.09	-0.36	2.03	121.7
25	Epoxy (100)	0.0665	74.73	0.29	86.82	0.15	0.14	50.0
Control	-----	0.2632	0.00	2.20	0.00	-0.34	2.54	115.5

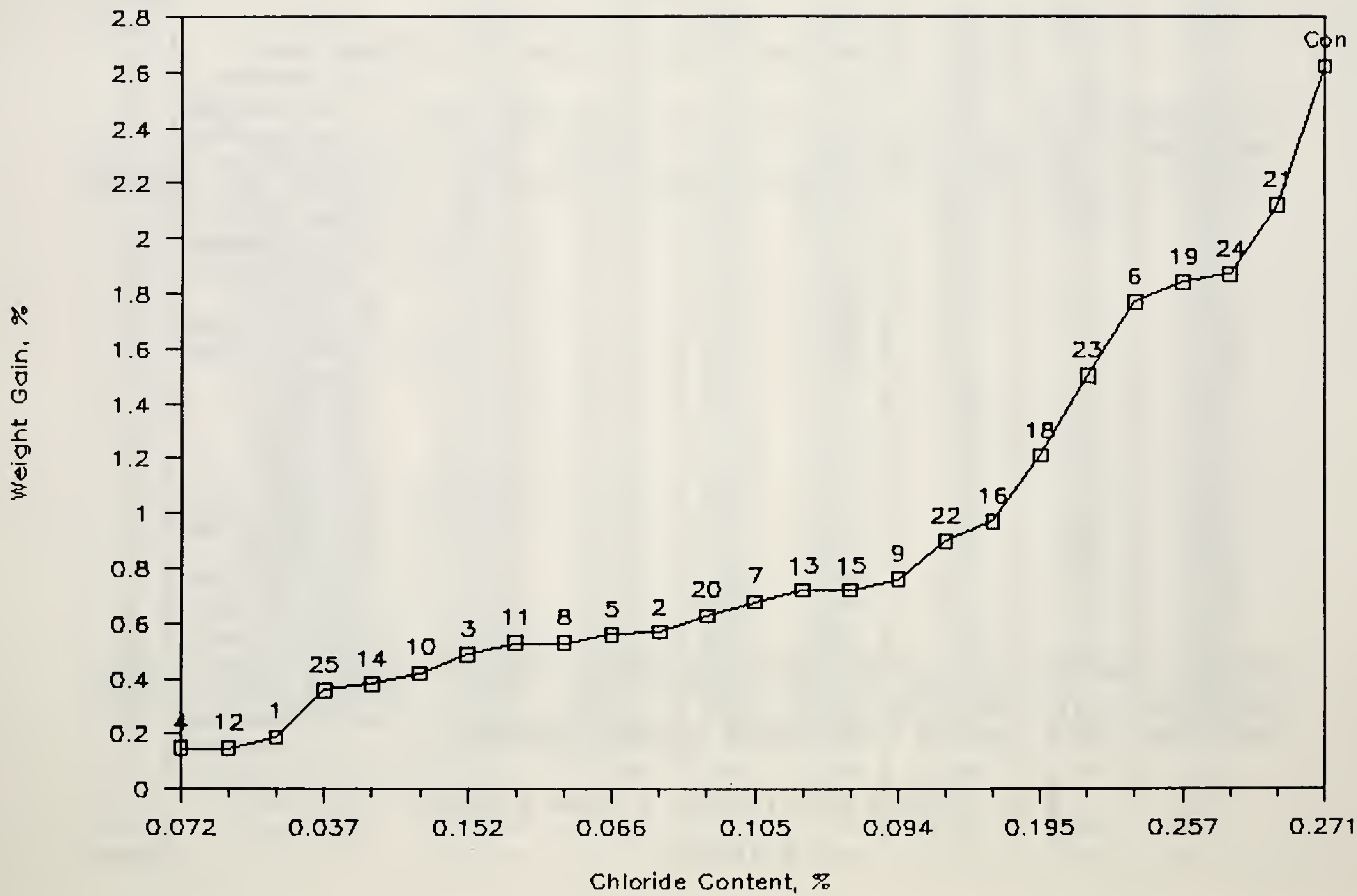

Figure C-4

Water Abs./Vapor Trans., Chloride Content Vs. Weight Gain - Set 1

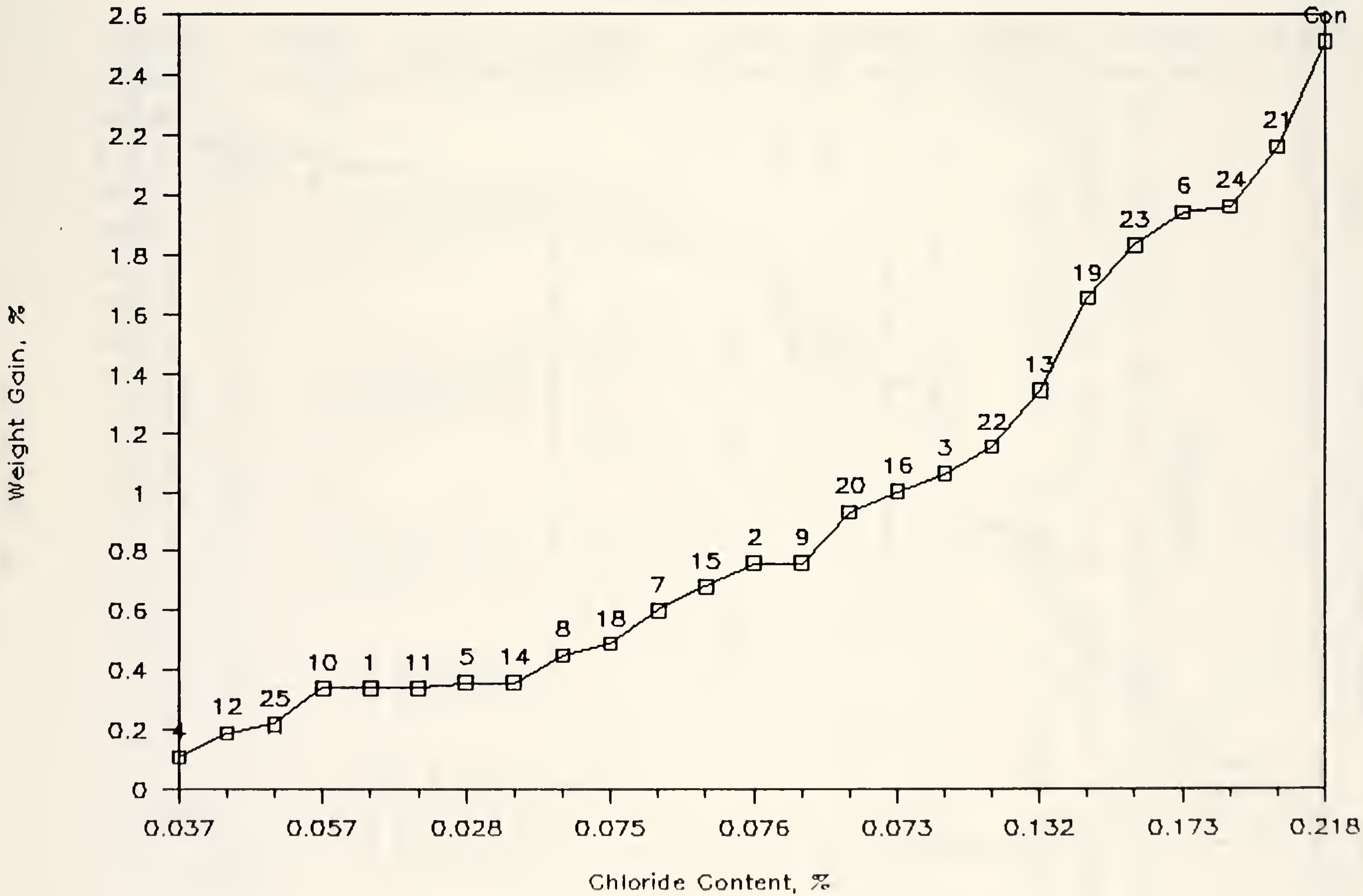

Figure C-5

Water Abs./Vapor Trans., Chloride Content Vs. Weight Gain - Set 2

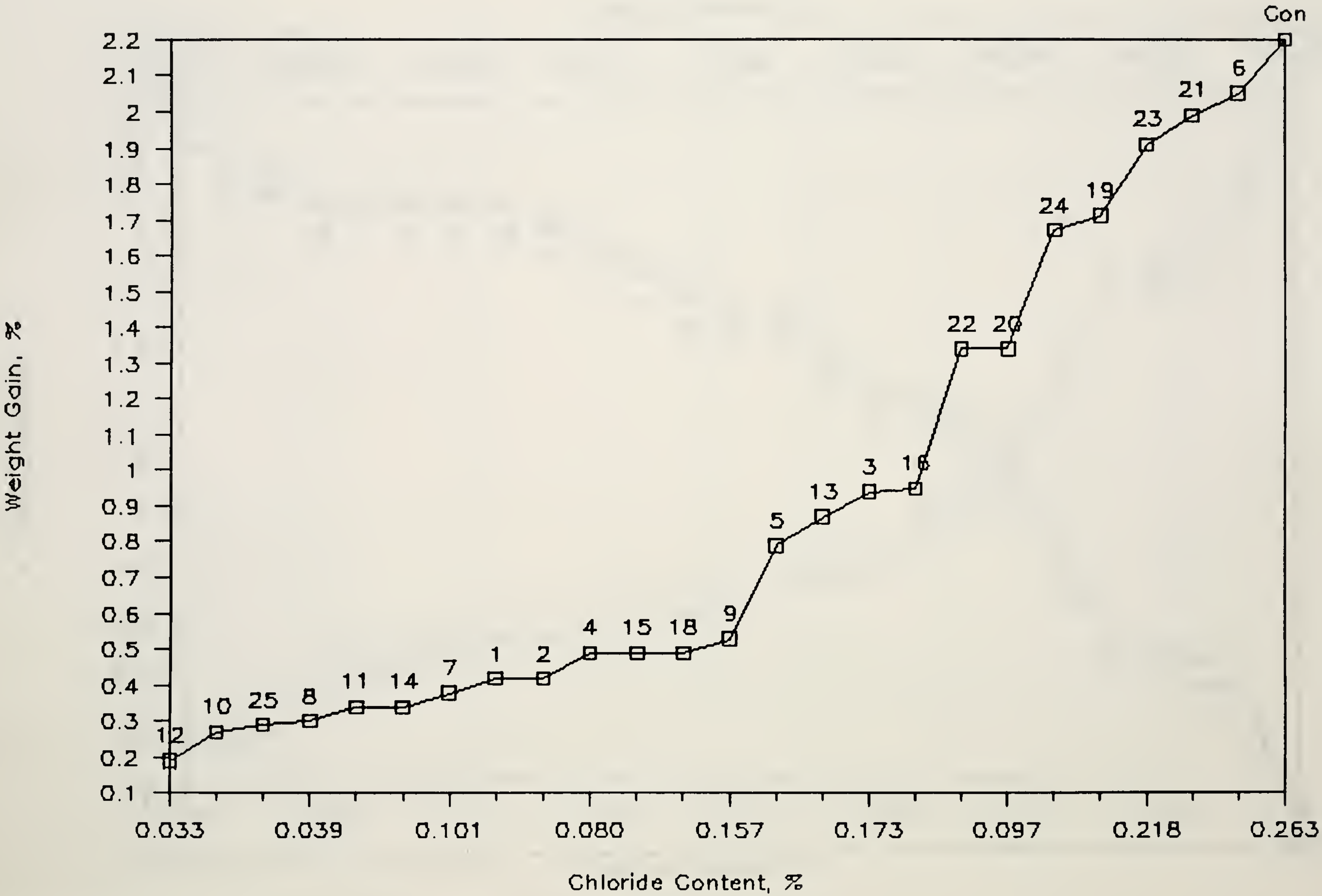

Figure C-6

Water Abs./Vapor Trans., Chloride Content Vs. Weight Gain - Set 3

- The temp. of the initial drying room varied +/- 6 degrees from 69 degrees F and the relative humidty was +/- 8% from 60% RH.

Conclusions

The following sections contain conclusions and recommendations that are based on the results from the water absorption, vapor transmission, and chloride ion content titration testing.

1. When the materials were applied to the concrete, the following ones demonstrated comparatively low water absorption, good vapor transmission, and very low chloride intrusion characteristics for their respective set:

Set 1 (coated at age 9 days)

Test No.	Weight Gain % by wt.	Weight Loss Weight Gain ratio, %	Chloride Ion Content % by wt.	Chemical Composition
12	0.15	1000.0	0.0437	Methyl methacrylate
1	0.19	420.0	0.0597	Epoxy, 50% solids
25	0.36	80.0	0.0367	Epoxy, 100% solids
11	0.53	300.0	0.0540	Silicone, 5% solids
8	0.53	300.0	0.0617	Silane, <20% solids
4	0.15	525.0	0.0723	Epoxy, 50% solids
Control	2.62	0.0	0.2710	

Appendix E of this report contains the results of the statistical analysis done on the soaking and drying data of the water absorption/vapor transmission test.

Set 2 (coated at age 19 days)

Test No.	Weight Gain % by wt.	Weight Loss Weight Gain ratio, %	Chloride Ion Content % by wt.	Chemical Composition
12	0.19	680.0	0.0380	Methyl methacrylate
4	0.11	466.7	0.0370	Epoxy, 50% solids
11	0.34	444.4	0.0388	Silicone, 5% solids
5	0.36	100.0	0.0275	Urethane, 55% solids
25	0.22	83.3	0.0236	Epoxy, 100% solids
10	0.34	366.7	0.0570	Silane, 40% solids
8	0.45	316.7	0.0428	Silane, <20% solids
Control	2.51	109.1	0.2175	

Set 3 (coated at age 28 days)

Test No.	Weight Gain % by wt.	Weight Loss Weight Gain ratio, %	Chloride Ion Content % by wt.	Chemical Composition
12	0.19	740.0	0.0328	Methyl methacrylate
8	0.30	462.5	0.0392	Silane, <20% solids
14	0.34	444.4	0.0385	Siloxane, 20% solids
11	0.34	455.6	0.0453	Silicone, 5% solids
10	0.27	485.7	0.0488	Silane, 40% solids
15	0.49	330.8	0.0402	Siloxane/Silicone
2	0.42	345.5	0.0545	Epoxy, 20% solids
Control	2.20	115.5	0.2632	

2. Epoxies. The five epoxies tested in this research were very effective in terms of their overall performance in the water absorption, vapor transmission, and chloride titration tests. The epoxies were more effective in terms of resisting chloride ion intrusion with respect to the first two sets. The chloride resistance

of the five epoxies was just a little bit stronger in the second set. However, in terms of overall effectiveness, the five epoxy formulations, as a group, performed better in the first set. In other words, for epoxies to be most effective, in terms of their performance, they should be applied to new concrete in the early stages of the curing period. This conclusion follows the manufacturer's recommendations for coating after seven days. The effectiveness of the epoxies can be related to the number of coats. Sample Nos. 1 and 4 both received two coats and performed better than Sample Nos. 2 and 3 which only received one coat each. There was one exception to the above stated conclusions. Sample No. 25 (100 percent solids) performed best after being coated at the age of 19 days (Set 2). This material performed very well in each set in terms of resisting water absorption by only gaining between 0.22 and 0.36 percent of its weight. It only lost, however, between 50.0 and 83.3 percent of the weight that it gained. Its percent chloride content almost doubled in the third set compared to the first two.

3. Urethanes. The effectiveness of the urethanes in terms of reducing weight gain during soaking, allowing the concrete to breathe during drying, and resisting chloride penetration was found to be related to the percent solids content. The material with only 30 percent solids (No. 6), the moisture-cured urethane, was quite ineffective in all three sets. However, the material with 55 percent solids (No. 5) was much more effective in reducing the weight gain during soaking in all of the sets, but was between three to five times more effective against chloride intrusion in the second set compared

to the first and third sets, respectively. It reduced the chlorides by over 75, 87, and 63 percent compared to the untreated control specimen in the first, second, and third set, respectively. Material No. 5 could be coated anytime between age 9 and 19 days because coating at the earlier time allowed the concrete to transmit vapor better while coating at the latter time reduced the weight gain during soaking and resisted chlorides better.

4. Silanes. This generic type was very effective in terms of the water absorption and vapor transmission test. The effectiveness of the silanes in these two tests was also related to the percent solids content. Sample No. 10, with the highest solids content at 40 percent, performed better than all of the other silanes in each of the sets. The range between the four silanes in the first set was 0.42 to 0.76, 0.34 to 0.76 in the second set, and 0.27 to 0.53 in the third set. The effectiveness of the silanes against chlorides was only above average when compared to the other materials. Material No. 8 and 10 demonstrated improved chloride resistance from the first set to the last, with both reducing chloride penetration by over 81 percent in the final set compared to the control sample. Material No. 7 reduced chlorides by around 61 percent in the first and third sets and 80 percent in the second set compared to the control. Material No. 9's chloride resistance dropped from 65 percent to 40 percent from the first to the third set. Inspite of some of the above results, the silanes, as a generic type, should be applied to new concrete after the concrete has cured for a full 28 days.

5. Silicone. This generic type was one of the most effective

materials in this phase of the testing. The results of the water absorption, vapor transmission, and chloride titration tests indicate that it can be applied to new concrete between the age of 9 and 28 days. The results were nearly identical for Set 2 and Set 3 and were only slightly better than Set 1's results. However, the performance of this material was still much better than average in the first set. Material No. 11 reduced weight gain during soaking around 79, 86, and 84 percent compared to the control for each set respectively and reduced chloride intrusion by over 80 percent in all three sets. This leads to the conclusion that silicone can be applied during any stage of the curing period with only a slightly diminished performance resulting from earlier coating.

6. Methyl Methacrylates. Sample No. 12 consisting of an aklyl-alkoxy silane primer and a top coat of methyl methacrylate performed exceptionally well in all three sets. This material should be applied at the latter stage because of the improved performance of the silane at latter periods. The other material, a straight methyl methacrylate, was much less effective over all three sets. Its performance was a little better in the final set and should also be applied at the latter period.

7. Siloxane. This material was quite consistent and one of the most effective materials in reducing weight gain during soaking while allowing the concrete to breathe during drying. However, it was only just above average at resisting chloride intrusion at around 60 percent in the first two sets. The chloride resistance jumped to over 85 percent in the final set, though. Therefore, this material

should be applied at the latter stages of the curing period.

8. Siloxane/Silicone. This material, a combination of siloxane and silicone, was most effective in resisting water and chloride absorption and allowing the concrete to breathe in the third set. This material's performance was only average in the first two sets, but was well above average in the final set. This material should be applied after the concrete has cured to 28 days.

9. Blend of Silanes. This material, a combination of silanes and natural oils and resins, was much more effective in the last two sets compared to the first set. The results of the final set were only slightly better than the second set. This penetrant obtained the best results when it was applied to the concrete between 19 and 28 days after casting, which matches the recommendations of the manufacturer.

10. Poly-Siloxane/Hydrophobic-Fumed Silica. This material was very ineffective at reducing water and chloride absorption and allowing the concrete to transmit vapor. Based on the results of this test, this material should not be used.

11. Masonry Coatings. The masonry coatings, as a whole, were fairly ineffective in these tests across all three sets. The "best" masonry coating was the material based on a styrene/acrylic copolymer. These materials were most effective when they were applied during the earlier stages of the curing period.

Table C-9

Weight Change During Soaking - Set 1

Sample Number	Generic Type (Solids)	Soaking in 15% saltwater Weight change after days, % 3	6	9	12	15	18	21
1	Epoxy (50%)	0.08	0.15	0.15	0.15	0.15	0.15	0.19
2	Epoxy (20%)	0.30	0.45	0.45	0.49	0.53	0.53	0.57
3	Epoxy (50%)	0.30	0.45	0.45	0.45	0.49	0.49	0.49
4	Epoxy (50%)	0.11	0.11	0.11	0.11	0.15	0.15	0.15
5	Urethane (55%)	0.41	0.49	0.49	0.53	0.56	0.56	0.56
6	Urethane (30%)	1.43	1.62	1.62	1.70	1.70	1.77	1.77
7	Silane (40%)	0.30	0.49	0.53	0.60	0.60	0.64	0.68
8	Silane (<20%)	0.27	0.38	0.42	0.46	0.46	0.53	0.53
9	Silane (20%)	0.38	0.57	0.61	0.65	0.68	0.72	0.76
10	Silane (40%)	0.27	0.34	0.34	0.38	0.42	0.42	0.42
11	Silicone (5%)	0.30	0.38	0.41	0.42	0.49	0.53	0.53
12	Methyl Meth-acrylate (20%)	0.08	0.11	0.15	0.15	0.15	0.15	0.15
13	Methyl Meth-acrylate (30%)	0.42	0.57	0.65	0.68	0.68	0.72	0.72
14	Siloxane (20%)	0.15	0.27	0.30	0.34	0.30	0.38	0.38
15	Siloxane/ Silicone (10%)	0.38	0.46	0.53	0.57	0.57	0.65	0.72
16	Styrene/Acrylic Copolymer (75%)	0.56	0.71	0.78	0.85	0.89	0.93	0.97
18	Blend of Silanes (30%)	0.45	0.60	0.72	0.94	1.02	1.13	1.21
19	Vinyl Acrylic (58%)	0.77	1.11	1.33	1.55	1.66	1.77	1.84
20	Polyester Resin (60%)	0.37	0.48	0.52	0.63	0.63	0.63	0.63
21	Poly-siloxane/ Silica (7%)	0.91	1.44	1.81	1.97	1.97	2.12	2.12
22	Styrene/Acrylic Copolymer (61%)	0.52	0.64	0.75	0.82	0.82	0.90	0.90
23	Elastomeric Acyrlic	1.09	1.24	1.35	1.46	1.46	1.50	1.50
24	Acyrlic Resin	1.36	1.50	1.61	1.76	1.83	1.87	1.87
25	Epoxy (100%)	0.11	0.25	0.29	0.33	0.33	0.36	0.36
Control	----	2.17	2.47	2.51	2.58	2.62	2.62	2.62

Table C-10

Weight Change During Soaking - Set 2

Sample Number	Generic Type (Solids)	Soaking in 15% saltwater Weight change after days, % 3	6	9	12	15	18	21
1	Epoxy (50%)	0.15	0.23	0.27	0.27	0.34	0.34	0.34
2	Epoxy (20%)	0.27	0.38	0.53	0.53	0.72	0.76	0.76
3	Epoxy (50%)	0.64	0.83	0.95	0.95	0.98	0.98	1.06
4	Epoxy (50%)	0.08	0.11	0.11	0.11	0.11	0.11	0.11
5	Urethane (55%)	0.23	0.27	0.30	0.34	0.38	0.38	0.38
6	Urethane (30%)	1.52	1.71	1.79	1.83	1.94	1.94	1.94
7	Silane (40%)	0.34	0.42	0.45	0.49	0.57	0.57	0.60
8	Silane (<20%)	0.23	0.26	0.34	0.38	0.45	0.45	0.45
9	Silane (20%)	0.34	0.42	0.45	0.49	0.64	0.64	0.76
10	Silane (40%)	0.19	0.27	0.31	0.31	0.34	0.34	0.34
11	Silicone (5%)	0.23	0.23	0.27	0.31	0.34	0.34	0.34
12	Methyl Meth-acrylate (20%)	0.15	0.15	0.15	0.15	0.15	0.15	0.19
13	Methyl Meth-acrylate (30%)	0.61	0.88	1.03	1.09	1.22	1.22	1.03
14	Siloxane (20%)	0.19	0.23	0.27	0.27	0.34	0.34	0.38
15	Siloxane/ Silicone (10%)	0.27	0.38	0.49	0.53	0.61	0.61	0.68
16	Styrene/Acrylic Copolymer (75%)	0.48	0.59	0.70	0.81	0.89	0.99	1.00
18	Blend of Silanes (30%)	0.19	0.03	0.03	0.42	0.49	0.49	0.49
19	Vinyl Acrylic (58%)	0.63	0.77	1.03	1.25	1.36	1.47	1.65
20	Polyester Resin (60%)	0.45	0.63	0.78	0.82	0.93	0.93	0.93
21	Poly-siloxane/ Silica (7%)	0.57	0.99	1.67	1.97	2.08	2.08	2.16
22	Styrene/Acrylic Copolymer (61%)	1.30	1.44	0.74	0.85	0.96	1.04	1.15
23	Elastomeric Acyrlic	1.17	1.47	1.61	1.72	1.83	1.83	1.83
24	Acyrlic Resin	1.26	1.60	1.78	1.81	1.93	1.96	1.96
25	Epoxy (100%)	0.15	0.15	0.18	0.22	0.22	0.22	0.22
Control	----	2.17	2.32	2.44	2.44	2.48	2.48	2.51

Table C-11

Weight Change During Soaking - Set 3

Sample Number	Generic Type (Solids)	Soaking in 15% saltwater Weight change after days, % 3	6	9	12	15	18	21
1	Epoxy (50%)	0.30	0.34	0.34	0.38	0.38	0.38	0.42
2	Epoxy (20%)	0.19	0.23	0.23	0.30	0.38	0.38	0.42
3	Epoxy (50%)	0.60	0.79	0.79	0.87	0.91	0.91	0.94
4	Epoxy (50%)	0.42	0.49	0.49	0.49	0.49	0.49	0.49
5	Urethane (55%)	0.42	0.53	0.53	0.64	0.75	0.75	0.79
6	Urethane (30%)	1.74	1.89	1.93	2.01	2.05	2.05	2.05
7	Silane (40%)	0.19	0.23	0.27	0.31	0.38	0.38	0.38
8	Silane (<20%)	0.15	0.23	0.23	0.27	0.27	0.30	0.30
9	Silane (20%)	0.38	0.38	0.38	0.46	0.50	0.53	0.53
10	Silane (40%)	0.19	0.23	0.23	0.23	0.27	0.27	0.27
11	Silicone (5%)	0.19	0.23	0.23	0.27	0.34	0.34	0.34
12	Methyl Meth-acrylate (20%)	0.15	0.15	0.15	0.19	0.19	0.19	0.19
13	Methyl Meth-acrylate (30%)	0.42	0.53	0.61	0.72	0.87	0.87	0.87
14	Siloxane (20%)	0.11	0.23	0.23	0.27	0.30	0.30	0.34
15	Siloxane/ Silicone (10%)	0.23	0.34	0.34	0.42	0.49	0.49	0.49
16	Styrene/Acrylic Copolymer (75%)	0.55	0.66	0.70	0.77	0.92	0.95	0.95
18	Blend of Silanes (30%)	0.19	0.30	0.30	0.38	0.42	0.46	0.49
19	Vinyl Acrylic (58%)	0.62	0.88	0.95	1.24	1.46	1.60	1.71
20	Polyester Resin (60%)	0.59	0.73	0.77	0.95	1.10	1.14	1.34
21	Poly-siloxane/ Silica (7%)	0.60	1.05	1.43	1.73	1.95	1.99	1.99
22	Styrene/Acrylic Copolymer (61%)	0.37	0.60	0.82	1.04	1.26	1.34	1.34
23	Elastomeric Acyrlic	1.28	1.58	1.61	1.80	1.91	1.91	1.91
24	Acyrlic Resin	1.13	1.34	1.42	1.56	1.63	0.29	1.67
25	Epoxy (100%)	0.18	0.26	0.26	0.26	0.26	2.20	0.29
Control	----	1.90	2.05	2.05	2.16	2.20	2.20	2.20

Table C-12

Weight Change During Drying - Set 1

Sample Number	Generic Type (Solids)	Drying at 70F and 50% RH Weight change after days, % 3	6	9	12	15	18	21	24
1	Epoxy (50%)	0.08	0.04	0.04	0.04	0.00	0.00	0.00	-0.04
2	Epoxy (20%)	0.19	0.11	0.11	0.11	0.11	0.11	0.11	0.11
3	Epoxy (50%)	0.26	0.15	0.15	0.11	0.11	0.08	0.08	0.08
4	Epoxy (50%)	0.00	0.00	0.00	0.00	-0.04	-0.04	-0.04	-0.04
5	Urethane (55%)	0.45	0.41	0.41	0.41	0.38	0.38	0.38	0.38
6	Urethane (30%)	1.09	1.02	0.98	0.98	0.91	0.91	0.91	0.91
7	Silane (40%)	0.26	0.23	0.23	0.23	0.19	0.19	0.19	0.19
8	Silane (<20%)	0.19	0.15	0.15	0.15	0.15	0.15	0.15	0.15
9	Silane (20%)	0.34	0.30	0.30	0.30	0.27	0.27	0.27	0.27
10	Silane (40%)	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
11	Silicone (5%)	0.19	0.19	0.19	0.19	0.15	0.15	0.15	0.15
12	Methyl Meth-acrylate (20%)	0.00	-0.04	-0.04	-0.04	-0.08	-0.08	-0.08	-0.08
13	Methyl Meth-acrylate (30%)	0.46	0.38	0.34	0.34	0.30	0.30	0.30	0.30
14	Siloxane (20%)	0.04	0.04	0.04	0.04	0.00	0.00	0.00	0.00
15	Siloxane/ Silicone (10%)	0.38	0.34	0.34	0.34	0.30	0.30	0.30	0.30
16	Styrene/Acrylic Copolymer (75%)	0.52	0.48	0.48	0.48	0.45	0.41	0.41	0.41
18	Blend of Silanes (30%)	0.64	0.60	0.60	0.60	0.57	0.53	0.53	0.53
19	Vinyl Acrylic (58%)	1.22	1.11	1.03	1.03	0.96	0.96	0.96	0.96
20	Polyester Resin (60%)	0.30	0.26	0.26	0.26	0.22	0.22	0.22	0.22
21	Poly-siloxane/ Silica (7%)	1.29	1.17	1.17	1.17	1.13	1.10	1.10	1.10
22	Styrene/Acrylic Copolymer (61%)	0.64	0.60	0.52	0.52	0.45	0.45	0.45	0.45
23	Elastomeric Acyrlic	0.98	0.84	0.84	0.84	0.80	0.80	0.80	0.80
24	Acyrlic Resin	1.10	1.06	1.03	0.99	0.95	0.95	0.96	0.95
25	Epoxy (100%)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Control	----	1.19	1.76	1.57	1.57	1.54	1.50	1.50	1.50

Table C-12, continued

Sample Number	Generic Type (Solids)	Drying at 70F and 50% RH Weight change after days, % 27	30	33	36
1	Epoxy (50%)	-0.15	-0.03	-0.04	-0.06
2	Epoxy (20%)	-0.15	-0.06	-0.83	-1.06
3	Epoxy (50%)	-0.15	-0.49	-0.72	-0.94
4	Epoxy (50%)	-0.15	-0.31	-0.46	-0.65
5	Urethane (55%)	0.23	0.04	-0.11	-0.30
6	Urethane (30%)	0.57	0.04	-0.19	-0.45
7	Silane (40%)	0.00	-0.45	-0.79	-1.05
8	Silane (<20%)	-0.08	-0.53	-0.84	-1.07
9	Silane (20%)	0.00	-0.42	-0.72	-0.99
10	Silane (40%)	-0.11	-0.57	-0.87	-1.10
11	Silicone (5%)	-0.08	-0.49	-0.83	-1.06
12	Methyl Meth-acrylate (20%)	-0.03	-0.72	-1.10	-1.36
13	Methyl Meth-acrylate (30%)	0.04	-0.34	-0.65	-0.87
14	Siloxane (20%)	-0.23	-0.64	-0.98	-1.21
15	Siloxane/ Silicone (10%)	0.15	-0.34	-0.72	-0.95
16	Styrene/Acrylic Copolymer (75%)	0.15	-0.22	-0.59	-0.78
18	Blend of Silanes (30%)	0.26	-0.19	-0.57	-0.76
19	Vinyl Acrylic (58%)	0.66	0.37	0.04	-0.18
20	Polyester Resin (60%)	0.04	-0.30	-0.70	-0.92
21	Poly-siloxane/ Silica (7%)	0.72	0.19	-0.19	-0.38
22	Styrene/Acrylic Copolymer (61%)	0.26	-0.08	-0.41	-0.67
23	Elastomeric Acyrlic	0.58	0.29	0.00	-0.26
24	Acyrlic Resin	0.66	0.33	0.00	-0.22
25	Epoxy (100%)	0.25	0.25	0.22	0.07
Control	----	1.09	0.60	0.19	0.00

Table C-13

Weight Change During Drying - Set 2

Sample Number	Generic Type (Solids)	Drying at 70F and 50% RH Weight change after days, % 3	6	9	12	15	18	21	24
1	Epoxy (50%)	0.30	0.27	0.27	0.27	0.27	0.27	0.19	0.15
2	Epoxy (20%)	0.50	0.46	0.42	0.42	0.42	0.42	0.34	0.23
3	Epoxy (50%)	0.91	0.83	0.72	0.68	0.68	0.68	0.64	0.53
4	Epoxy (50%)	0.11	0.11	0.04	0.04	0.04	0.04	0.04	-0.04
5	Urethane (55%)	0.38	0.38	0.34	0.34	0.34	0.30	0.30	0.30
6	Urethane (30%)	1.60	1.45	1.33	1.33	1.33	1.22	1.14	0.95
7	Silane (40%)	0.45	0.42	0.38	0.38	0.38	0.34	0.26	0.19
8	Silane (<20%)	0.26	0.23	0.19	0.19	0.19	0.15	0.15	0.08
9	Silane (20%)	0.53	0.45	0.42	0.42	0.42	0.30	0.30	0.27
10	Silane (40%)	0.23	0.19	0.15	0.15	0.15	0.08	0.08	0.04
11	Silicone (5%)	0.23	0.16	0.08	0.08	0.08	0.08	0.08	0.00
12	Methyl Meth-acrylate (20%)	0.15	0.11	0.08	0.08	0.08	0.08	0.00	0.00
13	Methyl Meth-acrylate (30%)	1.19	1.03	0.99	0.96	0.96	0.96	0.84	0.73
14	Siloxane (20%)	0.31	0.23	0.23	0.23	0.23	0.15	0.15	0.04
15	Siloxane/ Silicone (10%)	0.49	0.42	0.42	0.42	0.42	0.42	0.38	0.30
16	Styrene/Acrylic Copolymer (75%)	0.78	0.70	0.66	0.66	0.66	0.66	0.55	0.41
18	Blend of Silanes (30%)	0.34	0.27	0.27	0.27	0.27	0.15	0.15	0.08
19	Vinyl Acrylic (58%)	1.29	1.10	1.10	1.10	1.07	0.92	0.88	0.74
20	Polyester Resin (60%)	0.74	0.67	0.67	0.67	0.67	0.52	0.48	0.37
21	Poly-siloxane/ Silica (7%)	1.78	1.59	1.55	1.55	1.52	1.40	1.25	1.10
22	Styrene/Acrylic Copolymer (61%)	0.96	0.89	0.85	0.81	0.81	0.78	0.70	0.56
23	Elastomeric Acyrlic	1.58	1.43	1.32	1.32	1.32	1.28	1.17	1.06
24	Acyrlic Resin	1.59	1.41	1.37	1.37	1.37	1.30	1.22	1.04
25	Epoxy (100%)	0.22	0.18	0.18	0.15	0.15	0.15	0.15	0.15
Control	----	2.02	1.75	1.68	1.68	1.64	1.52	1.41	1.26

Table C-13, continued

Sample Number	Generic Type (Solids)	Drying at 100F and 26% RH Weight change after days, % 27	30	33	36
1	Epoxy (50%)	-0.04	-0.15	-0.03	-0.34
2	Epoxy (20%)	-0.27	-0.46	-0.72	-0.80
3	Epoxy (50%)	0.15	0.00	-0.27	-0.38
4	Epoxy (50%)	-0.11	-0.19	-0.34	-0.41
5	Urethane (55%)	0.19	0.11	0.00	0.00
6	Urethane (30%)	0.27	0.04	-0.23	-0.30
7	Silane (40%)	-0.23	-0.42	-0.68	-0.79
8	Silane (<20%)	-0.45	-0.64	-0.90	-0.98
9	Silane (20%)	-0.15	-0.42	-0.61	-0.80
10	Silane (40%)	-0.38	-0.61	-0.80	-0.92
11	Silicone (5%)	-0.46	-0.73	-0.99	-1.18
12	Methyl Meth-acrylate (20%)	-0.25	-0.72	-0.94	-1.09
13	Methyl Meth-acrylate (30%)	0.15	-0.12	-0.34	-0.54
14	Siloxane (20%)	-0.46	-0.69	-0.92	-1.07
15	Siloxane/ Silicone (10%)	-0.30	-0.53	-0.76	-0.87
16	Styrene/Acrylic Copolymer (75%)	-0.08	-0.30	-0.52	-0.66
18	Blend of Silanes (30%)	-0.34	-0.61	-0.80	-0.91
19	Vinyl Acrylic (58%)	0.37	0.15	-0.04	-0.15
20	Polyester Resin (60%)	-0.08	-0.37	-0.56	-0.74
21	Poly-siloxane/ Silica (7%)	0.38	0.08	-0.11	-0.30
22	Styrene/Acrylic Copolymer (61%)	0.11	-0.15	-0.37	-0.59
23	Elastomeric Acyrlic	0.66	0.37	0.15	-0.04
24	Acyrlic Resin	0.59	0.33	0.11	-0.04
25	Epoxy (100%)	0.11	0.07	0.07	0.04
Control	----	0.42	0.15	-0.04	-0.23

Table C-14

Weight Change During Drying - Set 3

Sample Number	Generic Type (Solids)	Drying at 70F and 50% RH Weight change after days, %							
		3	6	9	12	15	18	21	24
1	Epoxy (50%)	0.38	0.30	0.30	0.23	0.19	0.11	0.08	0.04
2	Epoxy (20%)	0.30	0.23	0.19	0.15	0.11	0.00	0.00	-0.11
3	Epoxy (50%)	0.83	0.76	0.76	0.72	0.57	0.45	0.42	0.38
4	Epoxy (50%)	0.45	0.42	0.38	0.34	0.30	0.23	0.19	0.15
5	Urethane (55%)	0.75	0.75	0.72	0.68	0.64	0.53	0.49	0.45
6	Urethane (30%)	2.01	1.93	1.74	1.63	1.48	1.21	1.10	1.02
7	Silane (40%)	0.19	0.19	0.15	0.11	0.04	-0.04	-0.11	-0.15
8	Silane (<20%)	0.23	0.15	0.11	0.08	0.00	-0.08	-0.11	-0.15
9	Silane (20%)	0.46	0.38	0.30	0.23	0.15	0.04	0.00	-0.04
10	Silane (40%)	0.19	0.11	0.08	0.04	-0.08	-0.11	-0.15	-0.19
11	Silicone (5%)	0.19	0.15	0.08	0.00	-0.04	-0.15	-0.19	-0.23
12	Methyl Meth-acrylate (20%)	0.15	0.11	0.08	0.00	-0.04	-0.15	-0.19	-0.23
13	Methyl Meth-acrylate (30%)	0.68	0.65	0.57	0.53	0.46	0.30	0.23	0.19
14	Siloxane (20%)	0.19	0.11	0.08	0.04	-0.04	-0.11	-0.15	-0.19
15	Siloxane/ Silicone (10%)	0.38	0.34	0.23	0.19	0.15	0.04	-0.04	-0.04
16	Styrene/Acrylic Copolymer (75%)	0.73	0.66	0.59	0.55	0.44	0.29	0.26	0.22
18	Blend of Silanes (30%)	0.30	0.27	0.19	0.15	0.11	0.04	0.00	-0.08
19	Vinyl Acrylic (58%)	1.35	1.17	0.95	0.84	0.69	0.51	0.47	0.40
20	Polyester Resin (60%)	0.95	0.84	0.73	0.66	0.55	0.37	0.29	0.26
21	Poly-siloxane/ Silica (7%)	1.69	1.54	1.39	1.20	1.05	0.86	0.75	0.68
22	Styrene/Acrylic Copolymer (61%)	1.23	1.15	1.00	0.93	0.86	0.67	0.60	0.52
23	Elastomeric Acyrlic	1.54	1.43	1.25	1.14	1.06	0.95	0.84	0.81
24	Acyrlic Resin	1.34	1.24	1.09	0.98	0.87	0.69	0.62	0.55
25	Epoxy (100%)	0.26	0.26	0.22	0.22	0.22	0.18	0.18	0.15
Control	----	1.90	1.82	1.56	1.40	1.25	0.99	0.87	0.80

Table C-14, continued

Sample Number	Generic Type (Solids)	Drying at 100F and 26% RH Weight change after days, % 27	30	33	36
1	Epoxy (50%)	-0.08	-0.31	-0.38	-0.53
2	Epoxy (20%)	-0.42	-0.76	-0.83	-1.03
3	Epoxy (50%)	0.11	-0.15	-0.30	-0.45
4	Epoxy (50%)	0.08	-0.11	-0.19	-0.34
5	Urethane (55%)	0.38	0.19	0.08	-0.08
6	Urethane (30%)	0.57	0.30	0.15	0.00
7	Silane (40%)	-0.57	-0.88	-1.03	-1.22
8	Silane (<20%)	-0.50	-0.83	-0.95	-1.10
9	Silane (20%)	-0.38	-0.72	-0.84	-1.03
10	Silane (40%)	-0.49	-0.76	-0.87	-1.02
11	Silicone (5%)	-0.61	-0.91	-1.02	-1.21
12	Methyl Methacrylate (20%)	-0.57	-0.91	-0.98	-1.21
13	Methyl Methacrylate (30%)	-0.15	-0.49	-0.57	-0.76
14	Siloxane (20%)	-0.57	-0.87	-0.95	-1.18
15	Siloxane/ Silicone (10%)	-0.49	-0.83	-0.91	-1.13
16	Styrene/Acrylic Copolymer (75%)	-0.11	-0.44	-0.51	-0.70
18	Blend of Silanes (30%)	-0.42	-0.76	-0.80	-0.99
19	Vinyl Acrylic (58%)	0.11	-0.15	-0.22	-0.36
20	Polyester Resin (60%)	-0.11	-0.40	-0.55	-0.77
21	Poly-siloxane/ Silica (7%)	0.23	-0.11	-0.19	-0.41
22	Styrene/Acrylic Copolymer (61%)	0.11	-0.26	-0.37	-0.63
23	Elastomeric Acyrlic	0.48	0.22	0.11	-0.08
24	Acyrlic Resin	0.22	-0.08	-0.18	-0.36
25	Epoxy (100%)	0.18	0.18	0.18	0.15
Control	----	0.27	-0.11	-0.19	-0.34

Table C-15

Chloride Titration Results - Set 1

Sample Number	Generic Type (% solids)	Chloride Content, % at Depth, in. 0.50	1.00	1.50	Average
1	Epoxy (50)	0.1225	0.0305	0.0206	0.0597
2	Epoxy (20)	0.2580	0.0510	0.0285	0.1125
3	Epoxy (50)	0.3015	0.1060	0.0480	0.1518
4	Epoxy (50)	0.1165	0.0720	0.0285	0.0723
5	Urethane (55)	0.1365	0.0440	0.0170	0.0658
6	Urethane (30)	0.4550	0.1525	0.0340	0.2138
7	Silane (40)	0.2545	0.0360	0.0230	0.1045
8	Silane (<20)	0.1280	0.0200	0.0370	0.0617
9	Silane (20)	0.2290	0.0325	0.0195	0.0937
10	Silane (40)	0.2340	0.0430	0.0220	0.0997
11	Silicone (5)	0.1105	0.0345	0.0170	0.0540
12	Methyl Methacrylate (20)	0.0865	0.0210	0.0235	0.0437
13	Methyl Methacrylate (30)	0.1895	0.0535	0.0290	0.0907
14	Siloxane (20)	0.2335	0.0395	0.0225	0.0985
15	Siloxane/Silicone (10)	0.2250	0.0310	0.0230	0.0930
16	Styrene/Acrylic Coploymer (75)	0.2280	0.0300	0.0180	0.0920
18	Blend of Silanes (30)	0.4215	0.1310	0.0330	0.1952
19	Vinyl Acrylic (58)	0.5505	0.1795	0.0405	0.2568
20	Polyester Resin (60)	0.2275	0.0525	0.0210	0.1003
21	Poly-siloxane/Silica (7)	0.6440	0.1645	0.0345	0.2810
22	Styrene/Acrylic Coploymer (61)	0.2400	0.0375	0.0270	0.1015
23	Elastomeric Acrylic	0.4885	0.1495	0.0260	0.2213
24	Acyrlic Resin	0.6125	0.2055	0.0330	0.2837
25	Epoxy (100)	0.0535	0.0345	0.0220	0.0367
CONTROL	----	0.5795	0.1835	0.0500	0.2710

Table C-16

Chloride Titration Results - Set 2

Sample Number	Generic Type (% solids)	Chloride Content, % at Depth, in. 0.50	1.00	1.50	Average
1	Epoxy (50)	0.1015	0.0325	0.0225	0.0522
2	Epoxy (20)	0.1860	0.0280	0.0140	0.0760
3	Epoxy (50)	0.2360	0.0845	0.0265	0.1157
4	Epoxy (50)	0.0410	0.0305	0.0395	0.0370
5	Urethane (55)	0.0390	0.0245	0.0190	0.0275
6	Urethane (30)	0.4220	0.0805	0.0165	0.1730
7	Silane (40)	0.0750	0.0245	0.0260	0.0418
8	Silane (<20)	0.0710	0.0240	0.0335	0.0428
9	Silane (20)	0.2765	0.0630	0.0280	0.1225
10	Silane (40)	0.1315	0.0230	0.0165	0.0570
11	Silicone (5)	0.0775	0.0215	0.0175	0.0388
12	Methyl Methacrylate (20)	0.0735	0.0175	0.0230	0.0380
13	Methyl Methacrylate (30)	0.2715	0.0940	0.3000	0.1318
14	Siloxane (20)	0.1980	0.0325	0.0235	0.0847
15	Siloxane/Silicone (10)	0.2250	0.0620	0.0335	0.1068
16	Styrene/Acrylic Coploymer (75)	0.1725	0.0275	0.0175	0.0725
18	Blend of Silanes (30)	0.1550	0.0410	0.0280	0.0747
19	Vinyl Acrylic (58)	0.4630	0.1170	0.0310	0.2037
20	Polyester Resin (60)	0.2370	0.0340	0.0135	0.0948
21	Poly-siloxane/Silica (7)	0.5530	0.1445	0.0240	0.2405
22	Styrene/Acrylic Coploymer (61)	0.2270	0.0435	0.0270	0.0992
23	Elastomeric Acrylic	0.3750	0.0840	0.0220	0.1603
24	Acyrlic Resin	0.5355	0.1095	0.0245	0.2232
25	Epoxy (100)	0.0395	0.0220	0.0190	0.0268
CONTROL	----	0.4985	0.1360	0.0270	0.2175

Table C-17

Chloride Titration Results - Set 3

Sample Number	Generic Type (% solids)	Chloride Content, % at Depth, in. 0.50	1.00	1.50	Average
1	Epoxy (50)	0.1300	0.0295	0.0200	0.0598
2	Epoxy (20)	0.1275	0.0210	0.0150	0.0545
3	Epoxy (50)	0.3685	0.1735	0.0410	0.1943
4	Epoxy (50)	0.1540	0.0435	0.0415	0.0797
5	Urethane (55)	0.1820	0.0820	0.0260	0.0967
6	Urethane (30)	0.6055	0.2595	0.0560	0.3070
7	Silane (40)	0.2105	0.0710	0.0200	0.1005
8	Silane (<20)	0.0740	0.0220	0.0215	0.0392
9	Silane (20)	0.3335	0.1070	0.0295	0.1567
10	Silane (40)	0.0955	0.0235	0.0235	0.0488
11	Silicone (5)	0.0720	0.0290	0.0350	0.0453
12	Methyl Methacrylate (20)	0.0410	0.0310	0.0265	0.0328
13	Methyl Methacrylate (30)	0.1580	0.0335	0.0180	0.0698
14	Siloxane (20)	0.0590	0.0280	0.0285	0.0385
15	Siloxane/Silicone (10)	0.0735	0.0290	0.0180	0.0402
16	Styrene/Acrylic Coploymer (75)	0.1040	0.0285	0.0160	0.0495
18	Blend of Silanes (30)	0.1330	0.0240	0.0285	0.0618
19	Vinyl Acrylic (58)	0.3870	0.0650	0.0285	0.1602
20	Polyester Resin (60)	0.2160	0.0450	0.0285	0.0965
21	Poly-siloxane/Silica (7)	0.4585	0.1195	0.0280	0.2020
22	Styrene/Acrylic Coploymer (61)	0.2470	0.0640	0.0270	0.1127
23	Elastomeric Acrylic	0.4485	0.1860	0.0205	0.2183
24	Acyrlic Resin	0.4150	0.1115	0.0295	0.1973
25	Epoxy (100)	0.0895	0.0790	0.0310	0.0665
CONTROL	----	0.5335	0.2165	0.0395	0.2632

Table C-18

Individual Titration Results, Water Abs./Vapor Trans. - Set1

No. 1

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	2.93	6.65	4.790	0.075	0.170	0.1225
1.0	1.08	1.30	1.190	0.028	0.033	0.0305
1.5	1.22	0.81	1.013	0.031	0.021	0.0260
						0.0597

No. 2

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	9.79	10.42	10.105	0.250	0.266	0.2580
1.0	2.74	1.26	2.000	0.070	0.032	0.0510
1.5	1.06	1.19	1.125	0.027	0.030	0.0285
						0.1125

No. 3

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	19.59	4.04	11.815	0.500	0.103	0.3015
1.0	6.11	2.20	4.155	0.156	0.056	0.1060
1.5	1.85	1.93	1.890	0.047	0.049	0.0480
						0.1518

No. 4

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	7.50	1.63	4.565	0.191	0.042	0.1165
1.0	4.99	0.65	2.820	0.127	0.017	0.0720
1.5	1.39	0.88	1.135	0.035	0.022	0.0285
						0.0723

No. 5

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	7.09	3.62	5.355	0.181	0.092	0.1365
1.0	1.90	1.55	1.725	0.049	0.039	0.0440
1.5	0.62	0.70	0.660	0.016	0.018	0.0170
						0.0658

No. 6

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	25.21	10.48	17.845	0.643	0.267	0.4550
1.0	8.46	3.49	5.975	0.216	0.089	0.1525
1.5	1.34	1.34	1.340	0.034	0.034	0.0340
						0.2138

Table C-18, contiunued

			No. 7			
Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	7.32	12.63	9.975	0.187	0.322	0.2545
1.0	1.11	1.73	1.420	0.028	0.044	0.0360
1.5	0.91	0.92	0.915	0.023	0.023	0.0230
						0.1045

			No. 8			
Depth	lbs/cy	lbs/cy	Avg.	% chloride	% chloride	Average
0.5	5.51	4.54	5.025	0.140	0.116	0.1280
1.0	0.77	0.77	0.770	0.020	0.020	0.0200
1.5	0.92	2.00	1.460	0.023	0.051	0.0370
						0.0617

			No. 9			
Depth	lbs/cy	lbs/cy	Avg.	% chloride	% chloride	Average
0.5	7.53	10.44	8.985	0.192	0.266	0.2290
1.0	1.23	1.35	1.290	0.031	0.034	0.0325
1.5	0.80	0.75	0.775	0.020	0.019	0.0195
						0.0937

			No. 10			
Depth	lbs/cy	lbs/cy	Avg.	% chloride	% chloride	Average
0.5	4.06	14.28	9.170	0.104	0.364	0.2340
1.0	1.49	1.87	1.680	0.038	0.048	0.0430
1.5	0.90	0.84	0.870	0.023	0.021	0.0220
						0.0997

			No. 11			
Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	3.46	5.23	4.345	0.088	0.133	0.1105
1.0	1.01	1.70	1.355	0.026	0.043	0.0345
1.5	0.50	0.81	0.655	0.013	0.021	0.0170
						0.0540

			No. 12			
Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	2.90	3.88	3.390	0.074	0.099	0.0865
1.0	0.82	0.83	0.825	0.021	0.021	0.0210
1.5	0.85	0.99	0.920	0.022	0.025	0.0235
						0.0437

Table C-18, contiunued

No. 13

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	6.28	8.57	7.425	0.160	0.219	0.1895
1.0	1.30	2.92	2.110	0.033	0.074	0.0535
1.5	0.78	1.47	1.125	0.020	0.038	0.0290
						0.0907

No. 14

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	4.94	13.37	9.155	0.126	0.341	0.2335
1.0	1.62	1.50	1.560	0.041	0.038	0.0395
1.5	0.85	0.91	0.880	0.022	0.023	0.0225
						0.0985

No. 15

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	5.60	12.02	8.810	0.143	0.307	0.2250
1.0	1.14	1.29	1.215	0.029	0.033	0.0310
1.5	0.80	1.01	0.905	0.020	0.026	0.0230
						0.0930

No. 16

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	12.42	5.47	8.945	0.317	0.139	0.2280
1.0	1.63	0.74	1.185	0.041	0.019	0.0300
1.5	0.74	0.66	0.700	0.019	0.017	0.0180
						0.0920

No. 18

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	25.25	7.79	16.520	0.644	0.199	0.4215
1.0	8.33	1.94	5.135	0.213	0.049	0.1310
1.5	1.44	1.14	1.290	0.037	0.029	0.0330
						0.1952

No. 19

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	23.45	19.74	21.595	0.598	0.503	0.5505
1.0	7.82	6.26	7.040	0.199	0.160	0.1795
1.5	0.82	2.37	1.595	0.021	0.060	0.0405
						0.2568

No. 20

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	10.45	7.39	8.920	0.267	0.188	0.2275
1.0	2.04	2.06	2.050	0.052	0.053	0.0525
1.5	0.64	1.03	0.836	0.016	0.026	0.0210
						0.1003

Table C-18, contiunued

No. 21

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	31.94	18.60	25.270	0.814	0.474	0.6440
1.0	7.79	5.10	6.445	0.199	0.130	0.1645
1.5	0.90	1.81	1.355	0.023	0.046	0.0345
						0.2810

No. 22

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	13.20	5.60	9.400	0.337	0.143	0.2400
1.0	1.56	1.35	1.455	0.040	0.035	0.0375
1.5	0.76	1.39	1.075	0.019	0.035	0.0270
						0.1015

No. 23

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	16.58	21.71	19.145	0.423	0.554	0.4885
1.0	4.88	6.87	5.875	0.124	0.175	0.1495
1.5	0.79	1.25	1.020	0.020	0.032	0.0260
						0.2213

No. 24

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	22.04	26.00	24.020	0.562	0.663	0.6125
1.0	5.78	10.33	8.055	0.147	0.264	0.2055
1.5	1.34	1.24	1.290	0.034	0.032	0.0330
						0.2837

No. 25

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	2.90	1.29	2.095	0.074	0.033	0.0535
1.0	1.83	0.85	1.340	0.047	0.022	0.0345
1.5	1.14	0.59	0.865	0.029	0.015	0.0220
						0.0367

Control

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	24.68	20.78	22.730	0.629	0.530	0.5795
1.0	8.29	6.12	7.205	0.211	0.156	0.1835
1.5	1.95	1.95	1.950	0.050	0.050	0.0500
						0.2710

Table C-19

Individual Titration Results, Water Abs./Vapor Trans. - Set 2

No. 1

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	3.13	4.80	3.965	0.080	0.123	0.1015
1.0	1.01	1.53	1.270	0.026	0.039	0.0325
1.5	0.62	1.13	0.876	0.016	0.029	0.0225
						0.0522

No. 2

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	6.72	7.87	7.295	0.171	0.201	0.1860
1.0	1.17	1.03	1.100	0.030	0.026	0.0280
1.5	0.51	0.60	0.555	0.013	0.015	0.0140
						0.0760

No. 3

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	10.01	8.51	9.260	0.255	0.217	0.2360
1.0	4.04	2.60	3.320	0.103	0.066	0.0845
1.5	1.42	0.69	1.055	0.036	0.017	0.0265
						0.1157

No. 4

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	1.64	1.58	1.610	0.042	0.040	0.0410
1.0	1.47	0.90	1.185	0.038	0.023	0.0305
1.5	1.36	1.73	1.545	0.035	0.044	0.0395
						0.0370

No. 5

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	1.44	1.61	1.525	0.037	0.041	0.0390
1.0	1.20	0.76	0.980	0.030	0.019	0.0245
1.5	0.76	0.76	0.760	0.019	0.019	0.0190
						0.0275

No. 6

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	18.94	14.17	16.555	0.483	0.361	0.4220
1.0	3.60	2.71	3.155	0.092	0.069	0.0805
1.5	0.50	0.80	0.650	0.013	0.020	0.0165
						0.1730

Table C-19, contiuned

			No. 7			
Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	3.42	2.49	2.955	0.087	0.063	0.0750
1.0	0.86	1.08	0.970	0.022	0.027	0.0245
1.5	0.75	1.29	1.020	0.019	0.033	0.0260
						0.0418
			No. 8			
Depth	lbs/cy	lbs/cy	Avg.	% chloride	% chloride	Average
0.5	3.47	2.13	2.800	0.088	0.054	0.0710
1.0	1.07	0.84	0.955	0.027	0.021	0.0240
1.5	0.83	1.81	1.320	0.021	0.046	0.0335
						0.0428
			No. 9			
Depth	lbs/cy	lbs/cy	Avg.	% chloride	% chloride	Average
0.5	18.49	3.22	10.855	0.471	0.082	0.2765
1.0	4.09	0.86	2.475	0.104	0.022	0.0630
1.5	1.11	1.11	1.110	0.028	0.028	0.0280
						0.1225
			No. 10			
Depth	lbs/cy	lbs/cy	Avg.	% chloride	% chloride	Average
0.5	8.06	2.25	5.155	0.206	0.057	0.1315
1.0	1.17	0.61	0.890	0.030	0.016	0.0230
1.5	0.56	0.73	0.645	0.014	0.019	0.0165
						0.0570
			No. 11			
Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	2.51	3.55	3.030	0.064	0.091	0.0775
1.0	0.76	0.95	0.855	0.019	0.024	0.0215
1.5	0.77	0.59	0.680	0.020	0.015	0.0175
						0.0388
			No. 12			
Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	3.38	2.37	2.875	0.086	0.061	0.0735
1.0	0.78	0.60	0.690	0.020	0.015	0.0175
1.5	1.18	0.63	0.905	0.030	0.016	0.0230
						0.0380

Table C-19, contiuned

No. 13

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	1.37	19.93	10.650	0.035	0.508	0.2715
1.0	1.07	6.32	3.695	0.027	0.161	0.0940
1.5	1.36	1.00	1.180	0.035	0.025	0.0300
						0.1318

No. 14

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	12.53	3.03	7.780	0.319	0.077	0.1980
1.0	1.58	0.99	1.285	0.040	0.025	0.0325
1.5	0.84	1.02	0.930	0.021	0.026	0.0235
						0.0847

No. 15

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	12.27	5.39	8.830	0.313	0.137	0.2250
1.0	2.81	2.04	2.425	0.072	0.052	0.0620
1.5	1.81	0.84	1.325	0.046	0.021	0.0335
						0.1068

No. 16

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	7.54	5.99	6.765	0.192	0.153	0.1725
1.0	1.16	1.04	1.100	0.029	0.026	0.0275
1.5	0.60	0.78	0.690	0.015	0.020	0.0175
						0.0725

No. 18

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	7.74	4.44	6.090	0.197	0.113	0.1550
1.0	2.33	0.92	1.625	0.059	0.023	0.0410
1.5	1.57	0.64	1.105	0.040	0.016	0.0280
						0.0747

No. 19

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	14.07	22.25	18.160	0.359	0.567	0.4630
1.0	2.41	6.80	4.605	0.061	0.173	0.1170
1.5	1.56	0.86	1.210	0.040	0.022	0.0310
						0.2037

No. 20

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	6.10	12.50	9.300	0.155	0.319	0.2370
1.0	1.06	1.62	1.340	0.027	0.041	0.0340
1.5	0.58	0.45	0.515	0.015	0.012	0.0135
						0.0948

Table C-19, contiuned

No. 21

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	28.00	15.39	21.695	0.714	0.392	0.5530
1.0	7.03	4.32	5.675	0.179	0.110	0.1445
1.5	1.19	0.72	0.955	0.030	0.018	0.0240
						0.2405

No. 22

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	6.58	11.20	8.890	0.168	0.286	0.2270
1.0	1.64	1.75	1.695	0.042	0.045	0.0435
1.5	0.87	1.26	1.065	0.022	0.032	0.0270
						0.0992

No. 23

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	13.22	16.18	14.700	0.337	0.413	0.3750
1.0	2.34	4.25	3.295	0.060	0.108	0.0840
1.5	1.15	0.60	0.875	0.029	0.015	0.0220
						0.1603

No. 24

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	15.08	26.89	20.985	0.385	0.686	0.5355
1.0	2.50	6.06	4.280	0.064	0.155	0.1095
1.5	0.69	1.21	0.950	0.018	0.031	0.0245
						0.2232

No. 25

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	1.87	1.22	1.545	0.048	0.031	0.0395
1.0	1.04	0.71	0.875	0.026	0.018	0.0220
1.5	0.65	0.81	0.730	0.017	0.021	0.0190
						0.0268

Control

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	20.55	17.86	19.205	0.524	0.455	0.4895
1.0	6.46	4.19	5.325	0.165	0.107	0.1360
1.5	1.31	0.80	1.055	0.033	0.021	0.0270
						0.2175

Table C-20

Individual Titration Results, Water Abs./Vapor Trans. - Set 3

No. 1

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	4.26	5.92	5.090	0.109	0.151	0.1300
1.0	0.72	1.62	1.170	0.018	0.041	0.0295
1.5	0.78	0.79	0.785	0.020	0.020	0.0200
						0.0598

No. 2

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	3.78	6.24	5.010	0.096	0.159	0.1275
1.0	0.93	0.70	0.815	0.024	0.018	0.0210
1.5	0.55	0.64	0.595	0.014	0.016	0.0150
						0.0545

No. 3

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	3.66	25.24	14.450	0.093	0.644	0.3685
1.0	1.12	12.47	6.795	0.029	0.318	0.1735
1.5	1.07	2.14	1.605	0.027	0.055	0.0410
						0.1943

No. 4

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	3.17	8.89	6.030	0.081	0.227	0.1540
1.0	0.79	2.63	1.710	0.020	0.067	0.0435
1.5	2.41	0.86	1.635	0.061	0.022	0.0415
						0.0797

No. 5

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	9.36	4.92	7.140	0.239	0.125	0.1820
1.0	4.30	2.12	3.210	0.110	0.054	0.0820
1.5	0.95	1.10	1.025	0.024	0.028	0.0260
						0.0967

No. 6

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	22.87	24.64	23.755	0.583	0.628	0.6055
1.0	12.76	6.45	9.605	0.325	0.194	0.2595
1.5	3.44	0.93	2.185	0.088	0.024	0.0560
						0.3070

Table C-20, continued

No. 7

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	11.42	5.08	8.250	0.291	0.130	0.2105
1.0	2.89	2.68	2.785	0.074	0.068	0.0710
1.5	0.79	0.78	0.785	0.020	0.020	0.0200
						0.1005

No. 8

Depth	lbs/cy	lbs/cy	Avg.	% chloride	% chloride	Average
0.5	3.33	2.46	2.895	0.085	0.063	0.0740
1.0	0.88	0.81	0.845	0.023	0.021	0.0220
1.5	0.91	0.78	0.845	0.023	0.020	0.0215
						0.0392

No. 9

Depth	lbs/cy	lbs/cy	Avg.	% chloride	% chloride	Average
0.5	12.98	13.16	13.070	0.331	0.336	0.3335
1.0	6.70	1.69	4.195	0.171	0.043	0.1070
1.5	1.37	0.93	1.150	0.035	0.024	0.0295
						0.1567

No. 10

Depth	lbs/cy	lbs/cy	Avg.	% chloride	% chloride	Average
0.5	3.78	4.04	3.910	0.096	0.103	0.0995
1.0	0.79	1.05	0.920	0.020	0.027	0.0235
1.5	0.72	1.12	0.920	0.018	0.029	0.0235
						0.0488

No. 11

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	2.72	2.92	2.820	0.069	0.075	0.0720
1.0	0.69	1.58	1.135	0.018	0.040	0.0290
1.5	1.21	1.54	1.375	0.031	0.039	0.0350
						0.0453

No. 12

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	1.76	1.46	1.610	0.045	0.037	0.0410
1.0	1.57	0.85	1.210	0.040	0.022	0.0310
1.5	1.03	1.06	1.045	0.026	0.027	0.0265
						0.0328

Table C-20, continued

No. 13

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	10.41	2.00	6.205	0.265	0.051	0.1580
1.0	1.61	1.14	1.375	0.041	0.026	0.0335
1.5	0.59	0.81	0.700	0.015	0.021	0.0180
						0.0698

No. 14

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	2.83	1.82	2.325	0.072	0.046	0.0590
1.0	0.78	1.42	1.100	0.020	0.036	0.0280
1.5	1.29	0.93	1.110	0.033	0.024	0.0285
						0.0385

No. 15

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	2.45	3.30	2.875	0.063	0.084	0.0735
1.0	1.47	0.81	1.140	0.037	0.021	0.0290
1.5	0.74	0.66	0.700	0.019	0.017	0.0180
						0.0402

No. 16

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	3.95	4.19	4.070	0.101	0.107	0.1040
1.0	1.33	0.91	1.120	0.034	0.023	0.0285
1.5	0.58	0.69	0.635	0.015	0.017	0.0160
						0.0495

No. 18

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	6.82	3.59	5.205	0.174	0.092	0.1330
1.0	0.81	1.05	0.930	0.021	0.027	0.0240
1.5	1.53	0.71	1.120	0.039	0.018	0.0285
						0.0618

No. 19

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	15.53	14.81	15.170	0.396	0.378	0.3870
1.0	3.21	1.89	2.550	0.082	0.048	0.0650
1.5	1.61	0.63	1.120	0.041	0.016	0.0285
						0.1602

No. 20

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	4.80	12.15	8.475	0.122	0.310	0.2160
1.0	1.83	1.67	1.750	0.047	0.043	0.0450
1.5	1.39	0.88	1.135	0.035	0.022	0.0285
						0.0965

Table C-20, continued

No. 21

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	17.95	18.01	17.980	0.458	0.459	0.4585
1.0	4.66	4.71	4.685	0.119	0.120	0.1195
1.5	1.29	0.89	1.090	0.033	0.023	0.0280
						0.2020

No. 22

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	8.44	10.96	9.700	0.215	0.279	0.2470
1.0	1.56	3.45	2.505	0.040	0.088	0.0640
1.5	1.44	0.66	1.050	0.037	0.017	0.0270
						0.1127

No. 23

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	18.29	16.91	17.600	0.466	0.431	0.4485
1.0	7.71	6.88	7.295	0.197	0.175	0.1860
1.5	0.95	0.69	0.820	0.024	0.017	0.0205
						0.2183

No. 24

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	15.86	19.52	17.690	0.404	0.498	0.4510
1.0	3.59	5.19	4.390	0.091	0.132	0.1115
1.5	0.64	1.67	1.155	0.016	0.043	0.0295
						0.1973

No. 25

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	6.07	0.96	3.515	0.155	0.024	0.0895
1.0	5.34	0.86	3.100	0.136	0.022	0.0790
1.5	1.17	1.25	1.210	0.030	0.032	0.0310
						0.0665

Control

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	21.93	19.91	20.920	0.559	0.508	0.5335
1.0	10.32	6.66	8.490	0.263	0.170	0.2165
1.5	2.19	0.92	1.555	0.056	0.023	0.0395
						0.2632

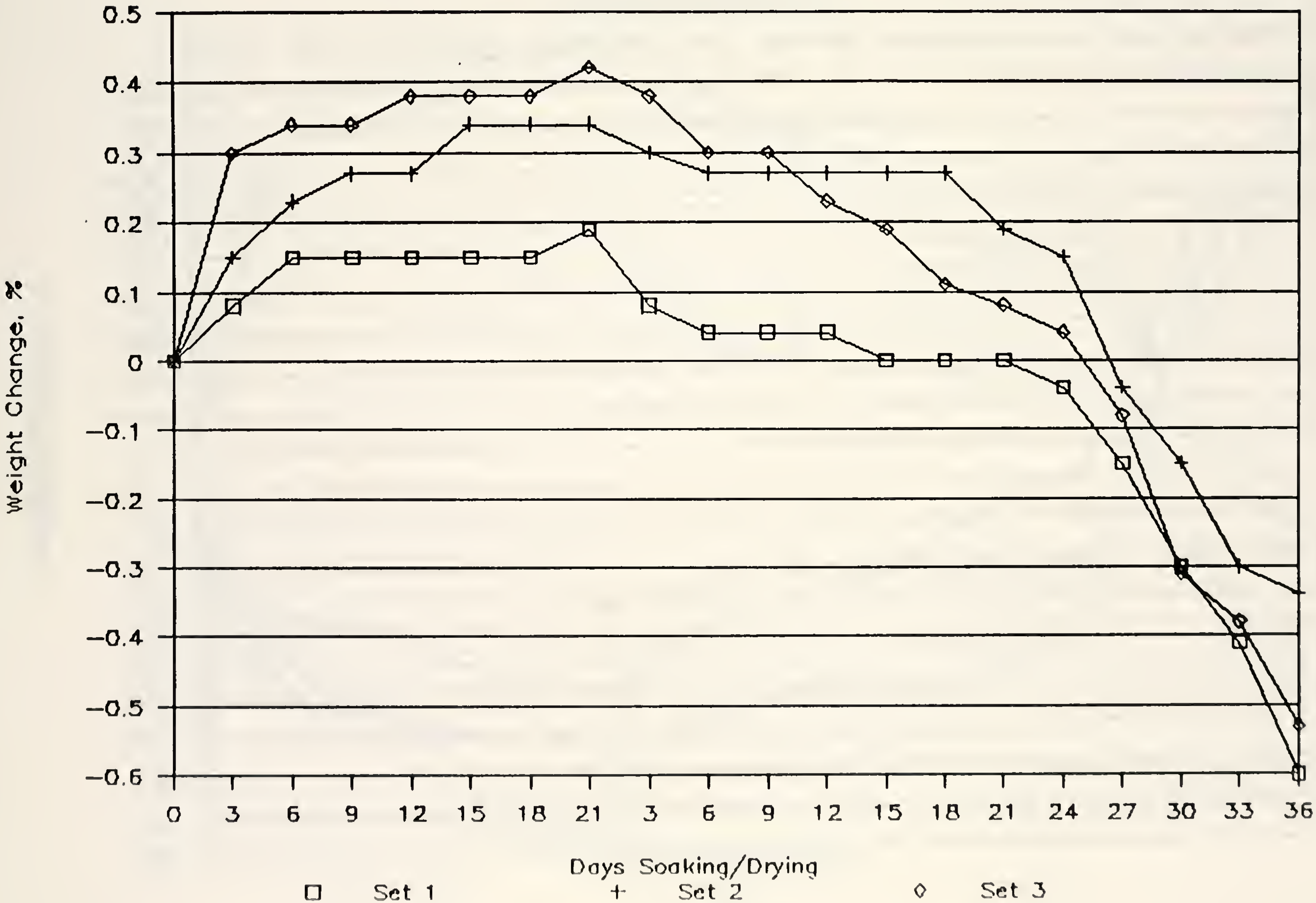

Figure C-7

Water Abs./Vapor Trans., Weight Change, Epoxy - No. 1

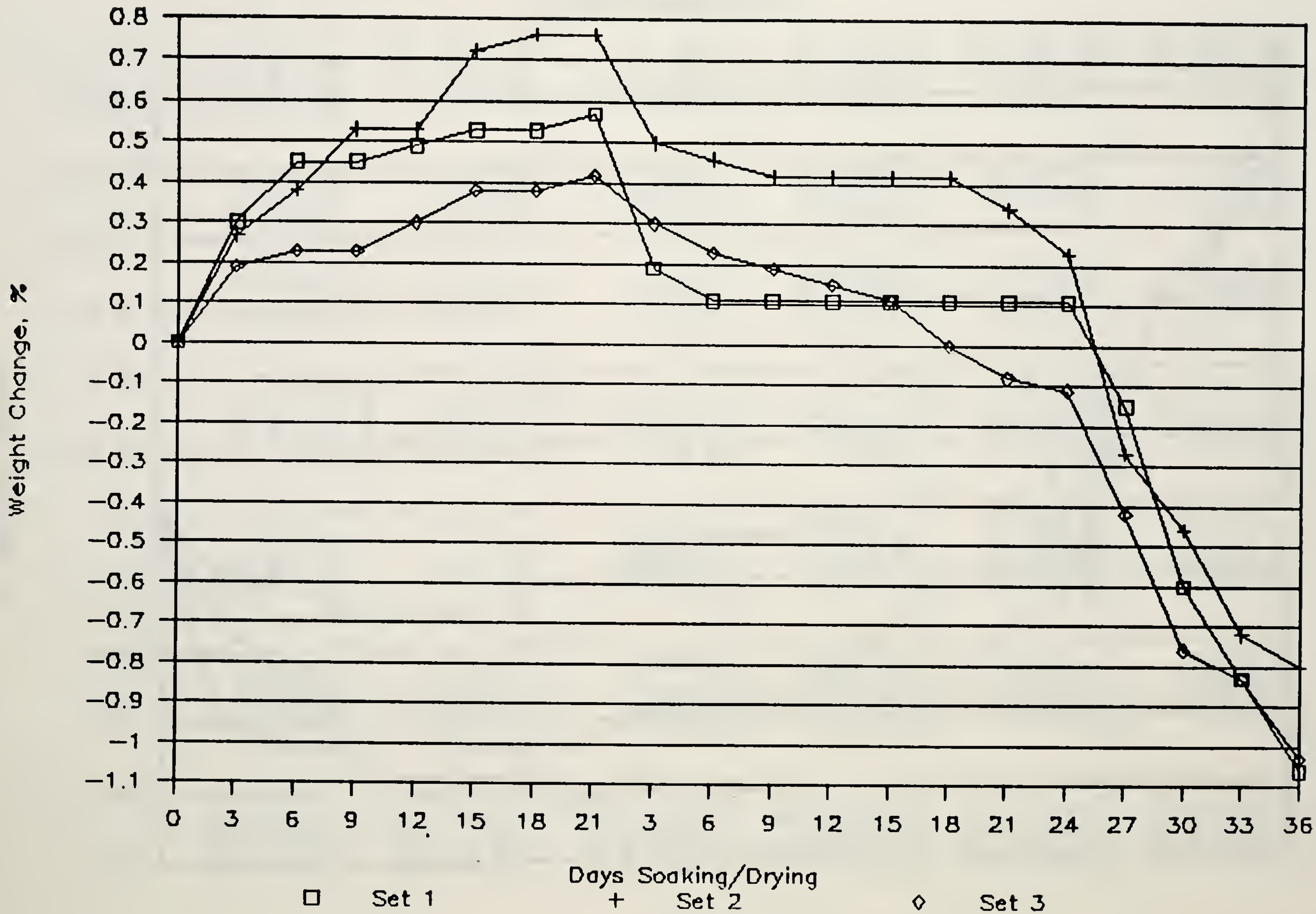

Figure C-8

Water Abs./Vapor Trans., Weight Change, Epoxy - No. 2

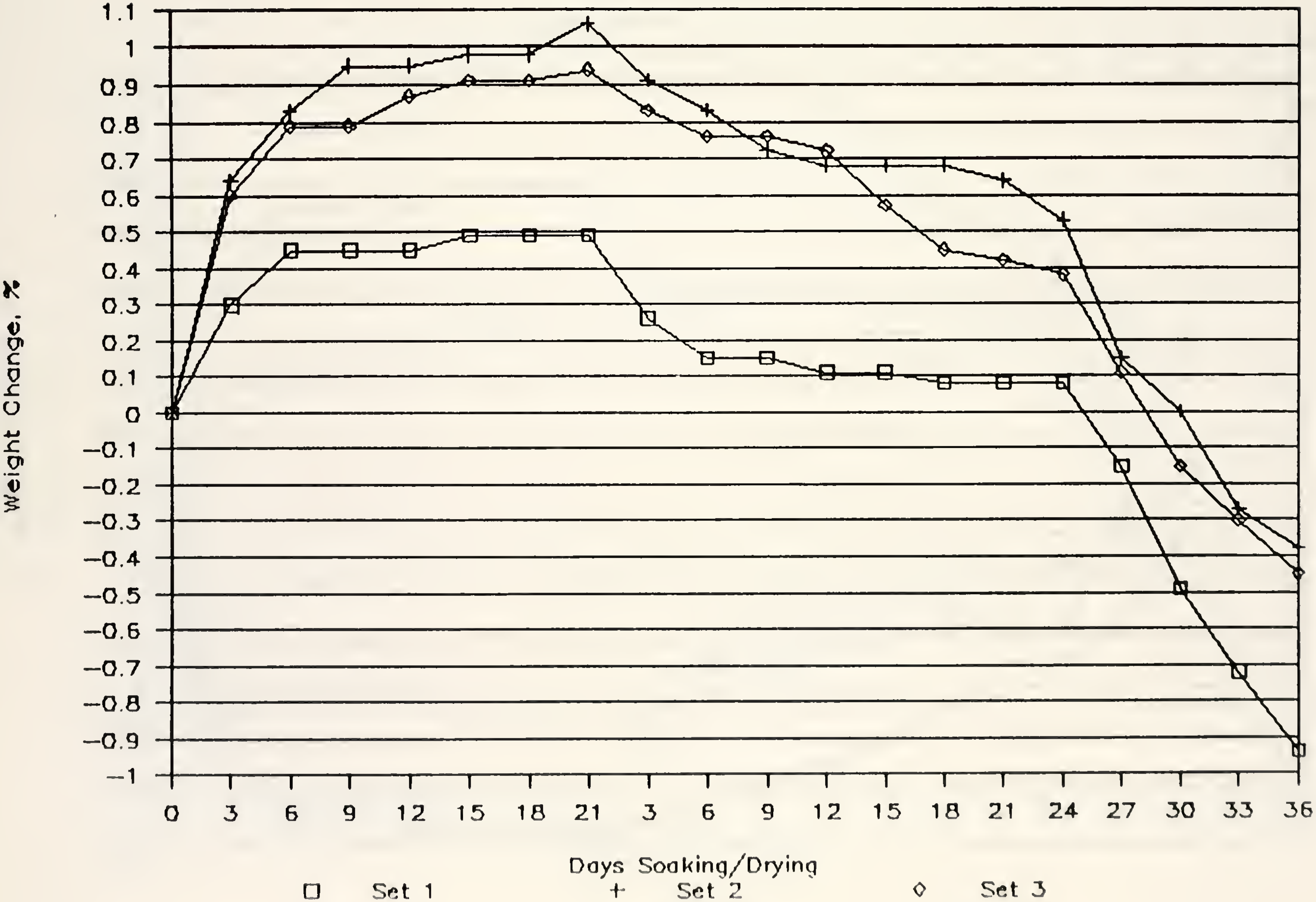

Figure C-9

Water Abs./Vapor Trans., Weight Change, Epoxy - No. 3

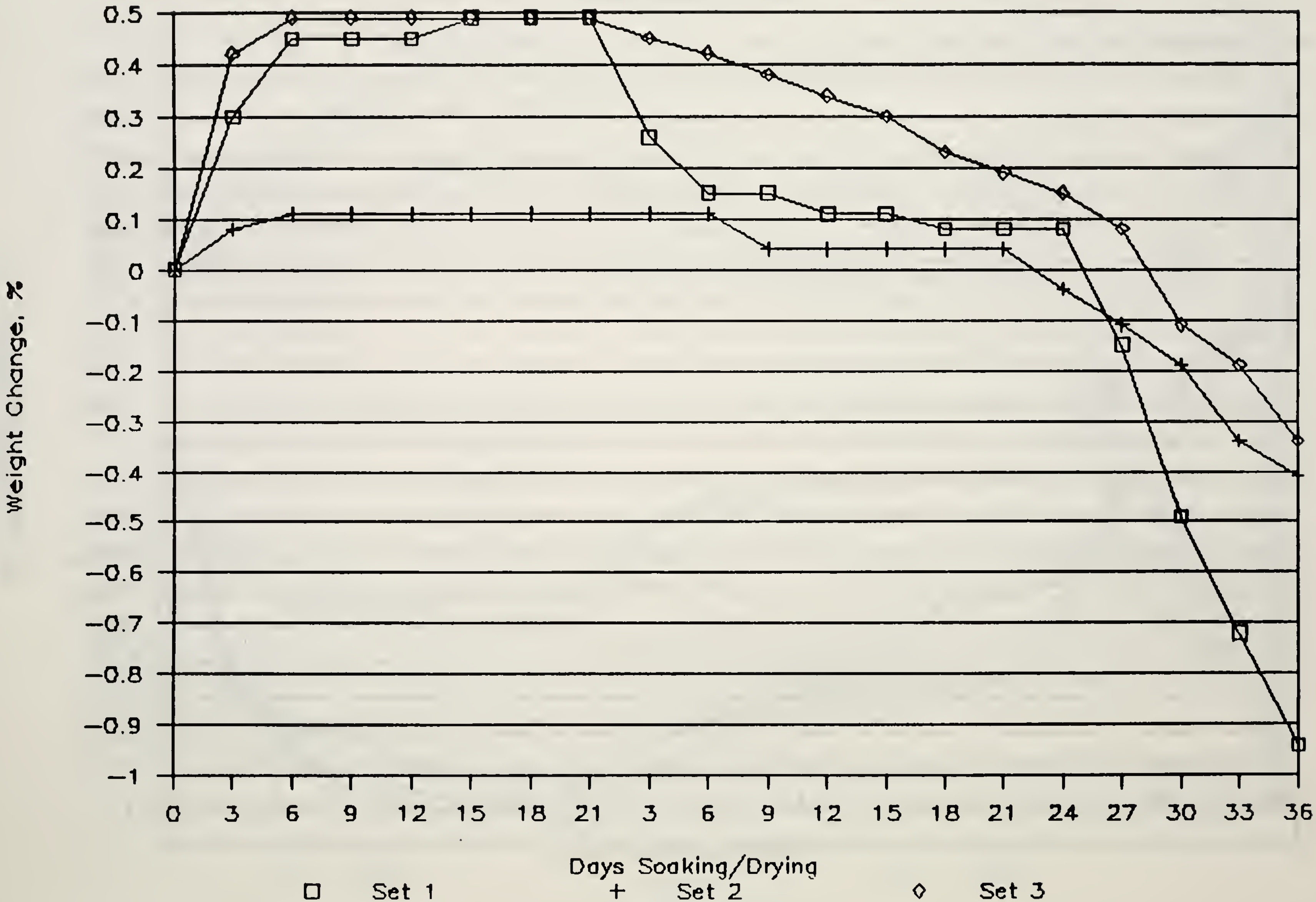

Figure C-10

Water Abs./Vapor Trans., Weight Change, Epoxy - No. 4

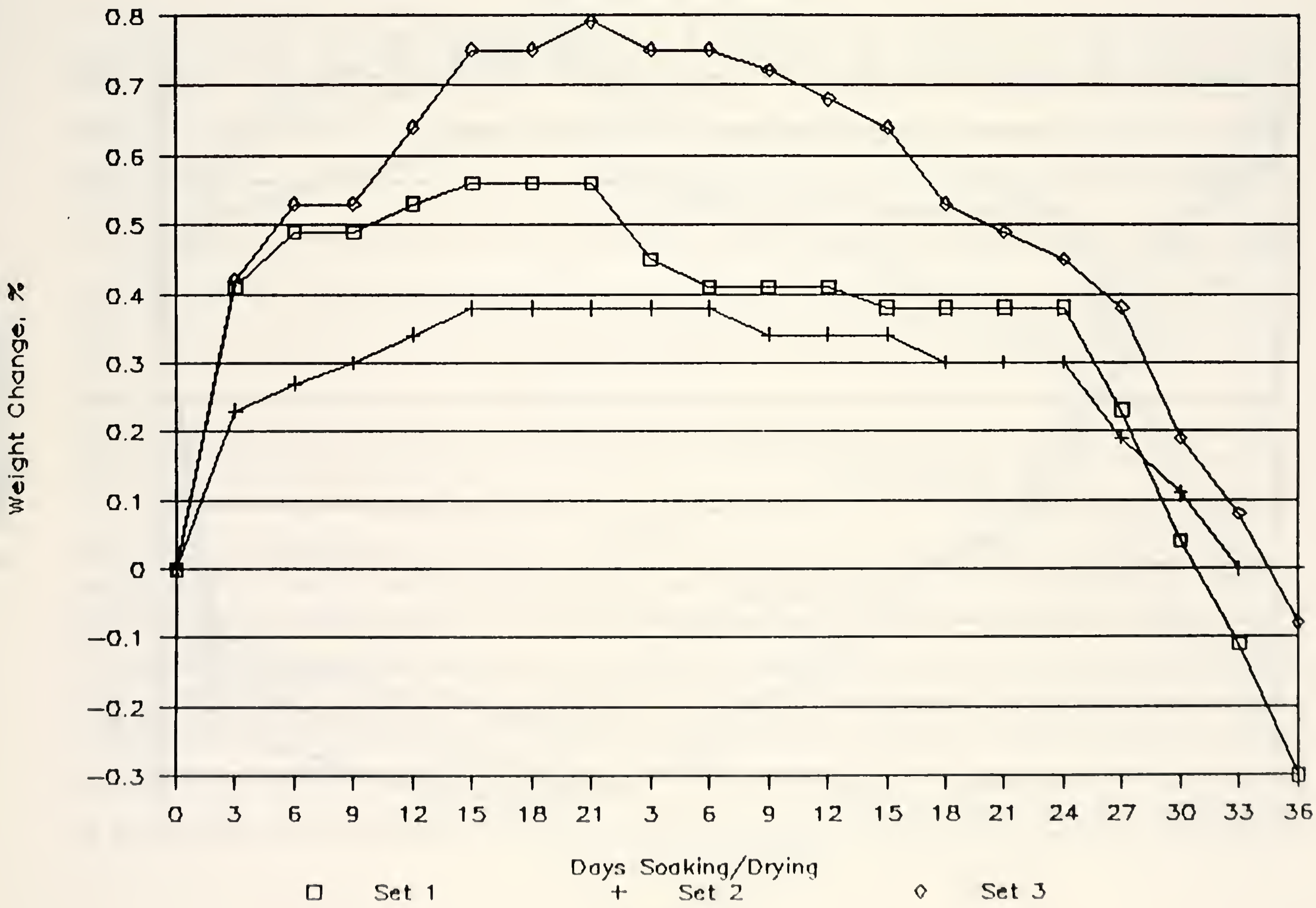

Figure C-11

Water Abs./Vapor Trans., Weight Change, Urethane - No. 5

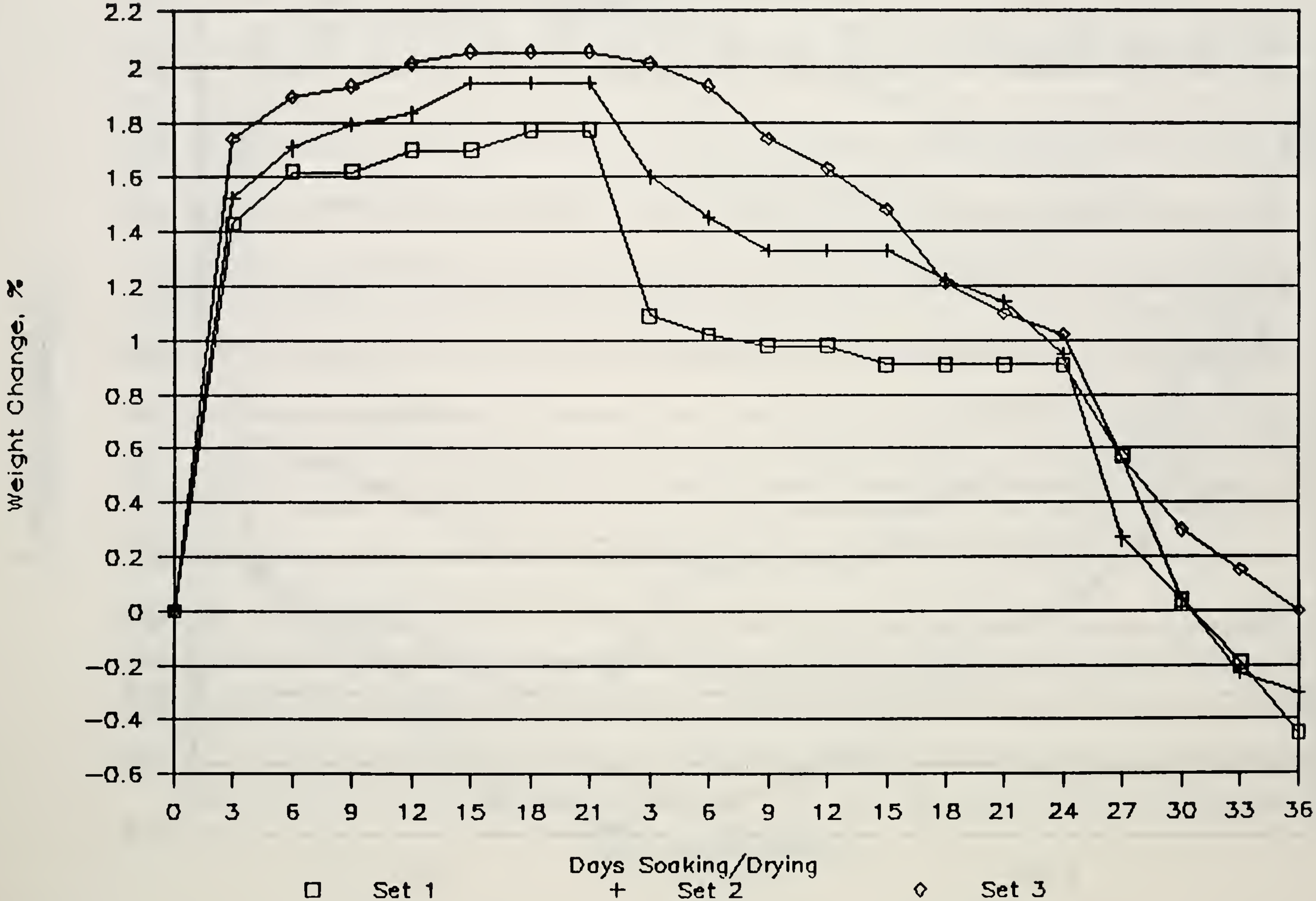
Weight Change, %
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
0 3 6 9 12 15 18 21 3 6 9 12 15 18 21 24 27 30 33 36
Days Soaking/Drying
Set 1
Set 2
Set 3

Figure C-12

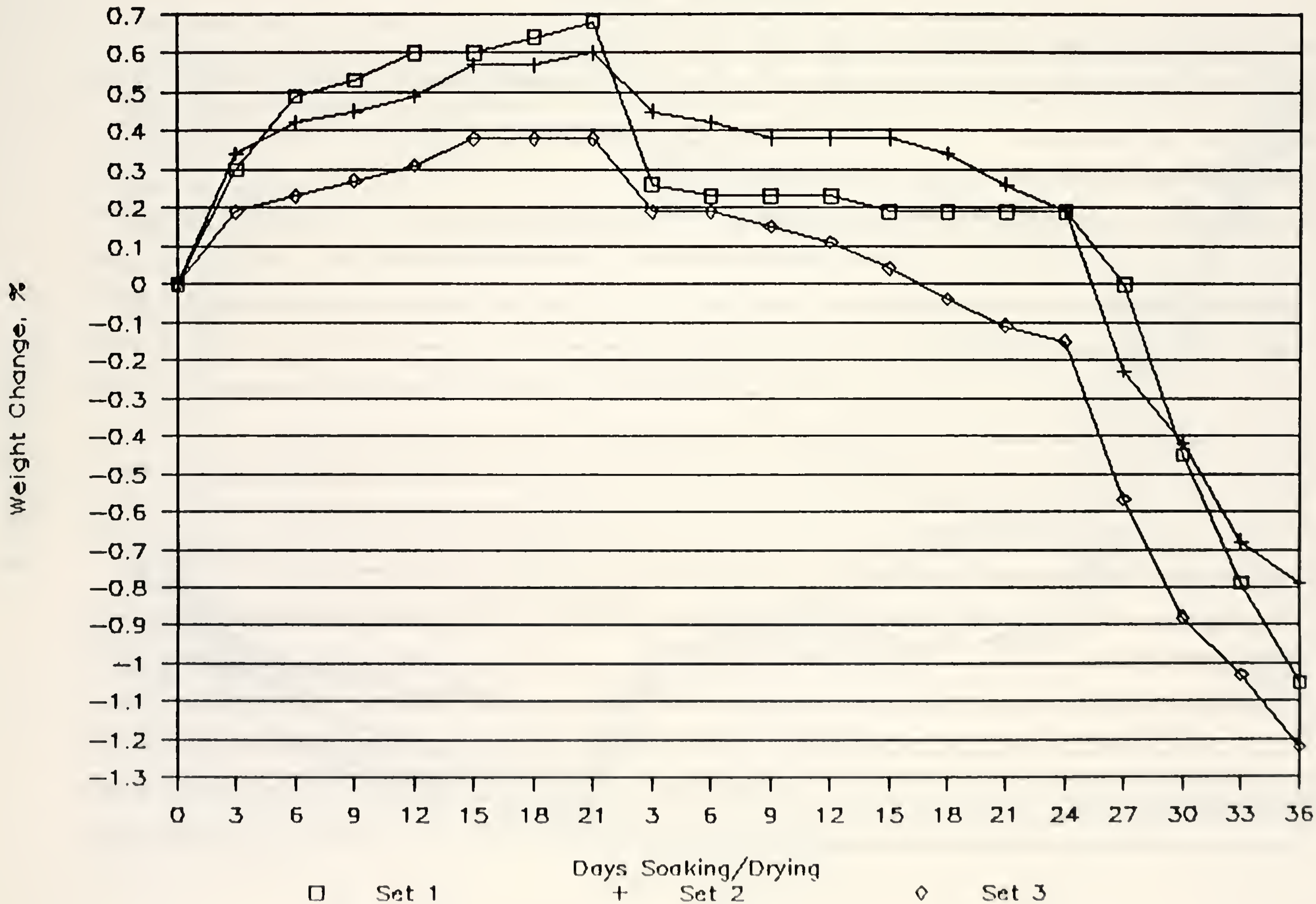

Figure C-13

Water Abs./Vapor Trans., Weight Change, Silane - No. 7

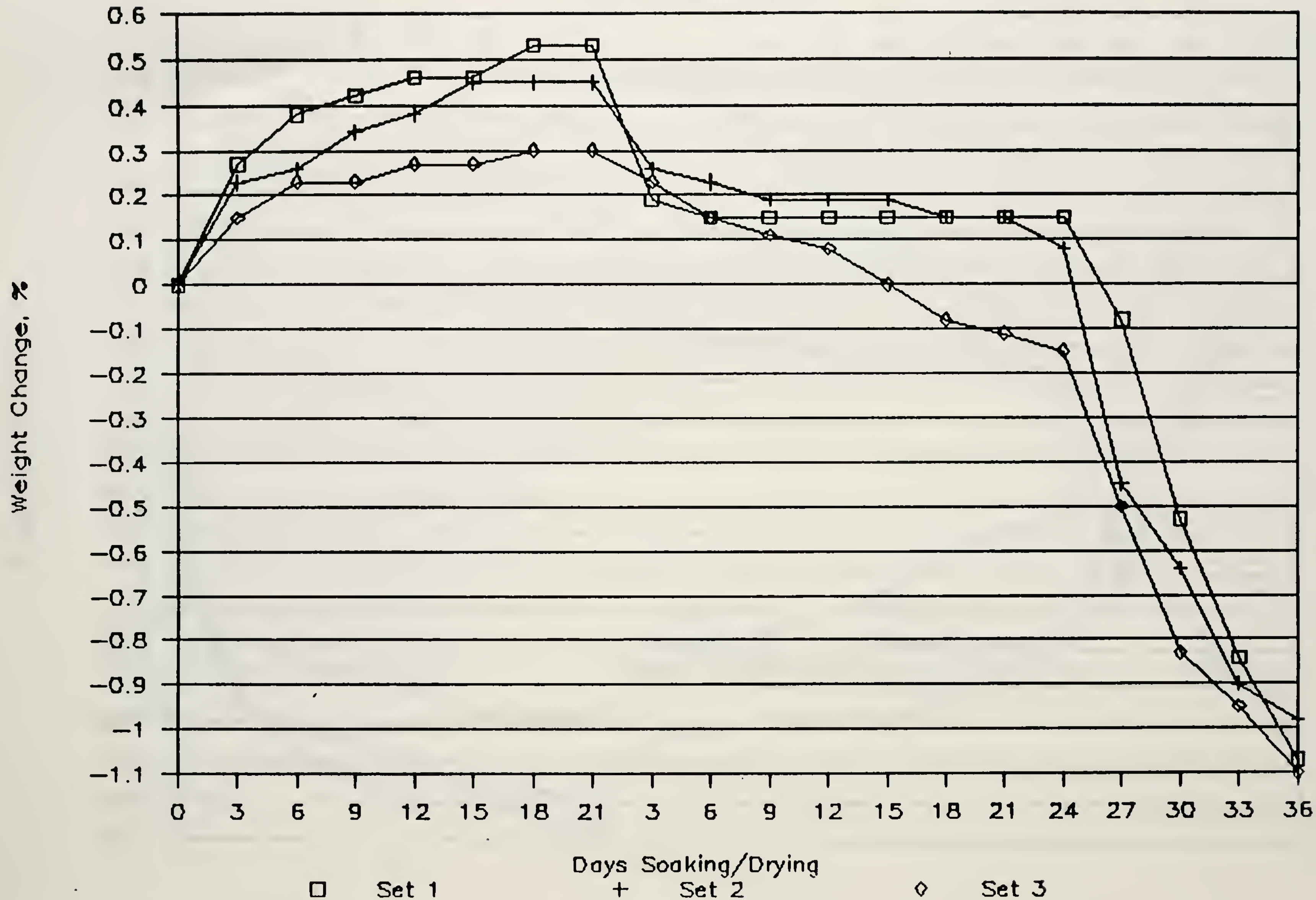

Figure C-14

Water Abs./Vapor Trans., Weight Change, Silane - No. 8

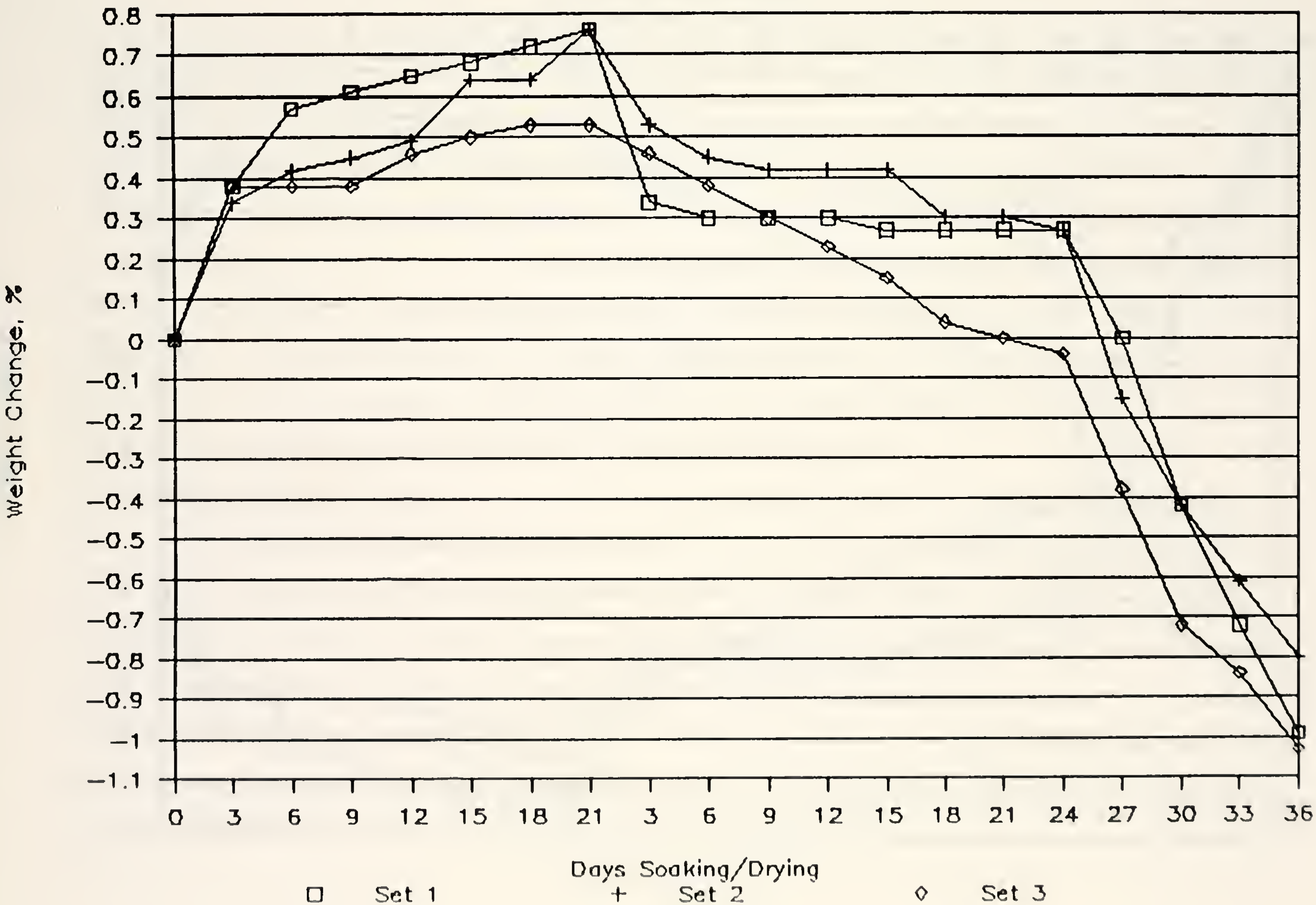

Figure C-15

Water Abs./Vapor Trans., Weight Change, Silane - No. 9

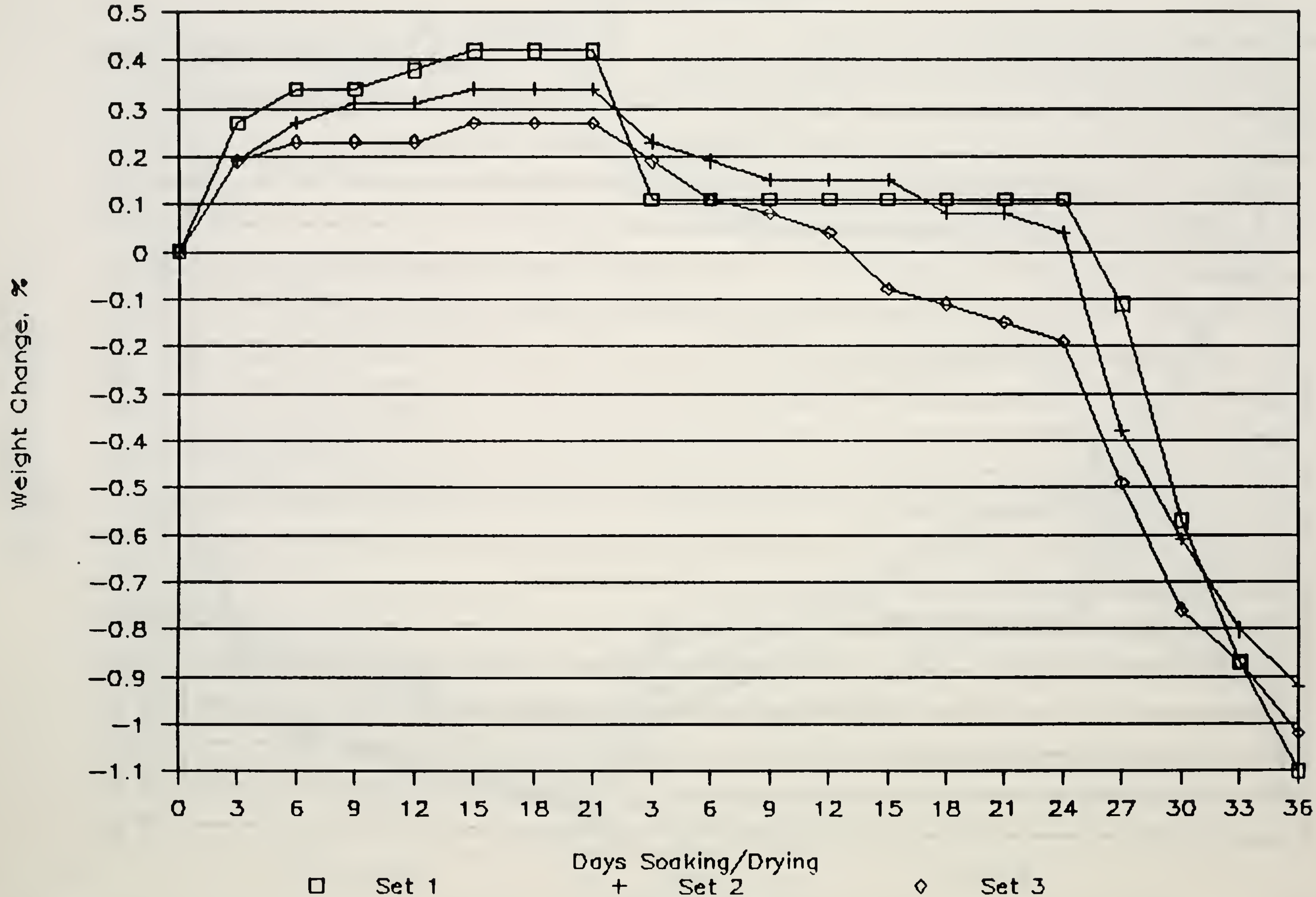

Figure C-16

Water Abs./Vapor Trans. Weight Change, Silane, No. 10

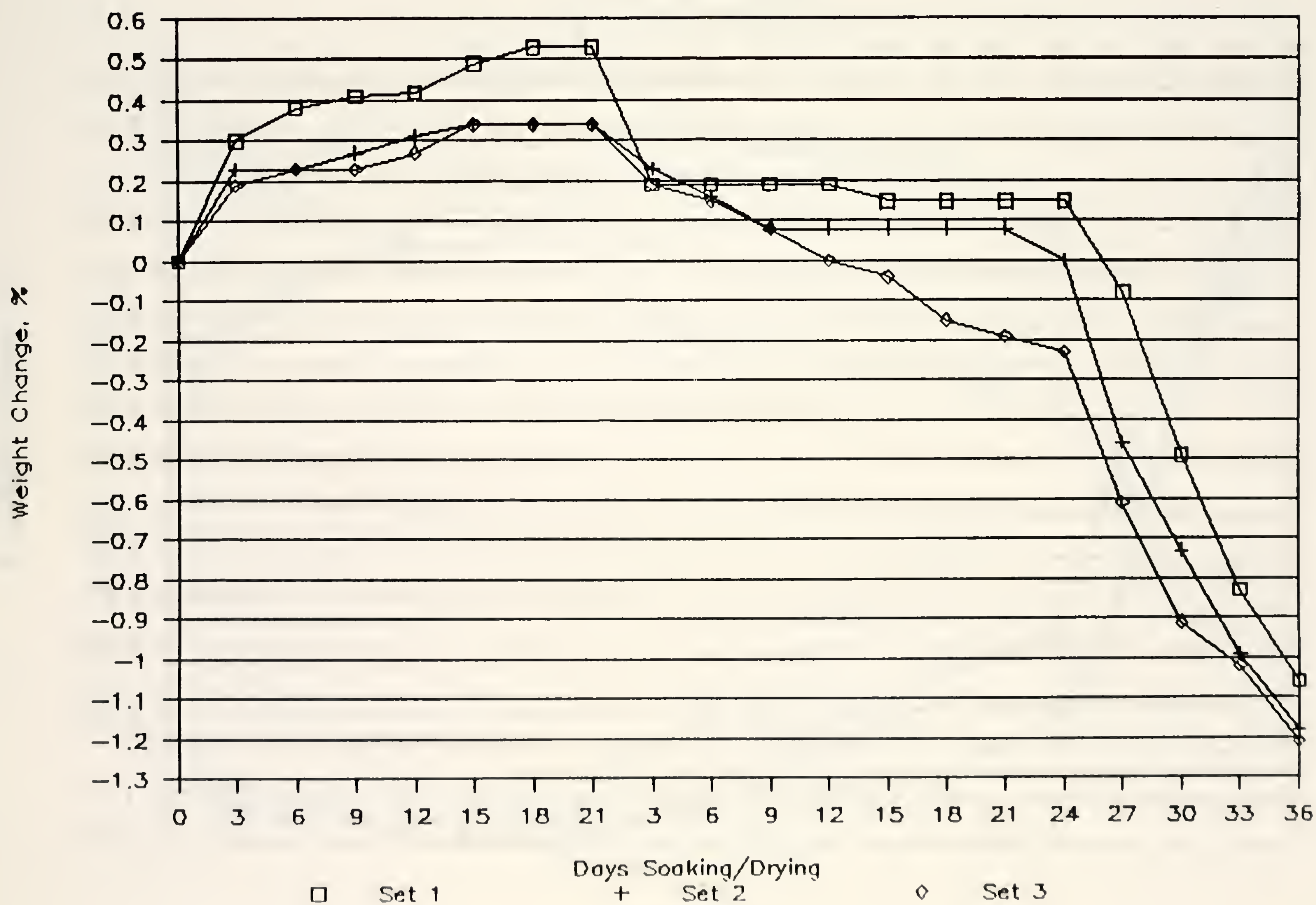

Figure C-17

Water Abs./Vapor Trans., Weight Change, Silicone - No. 11

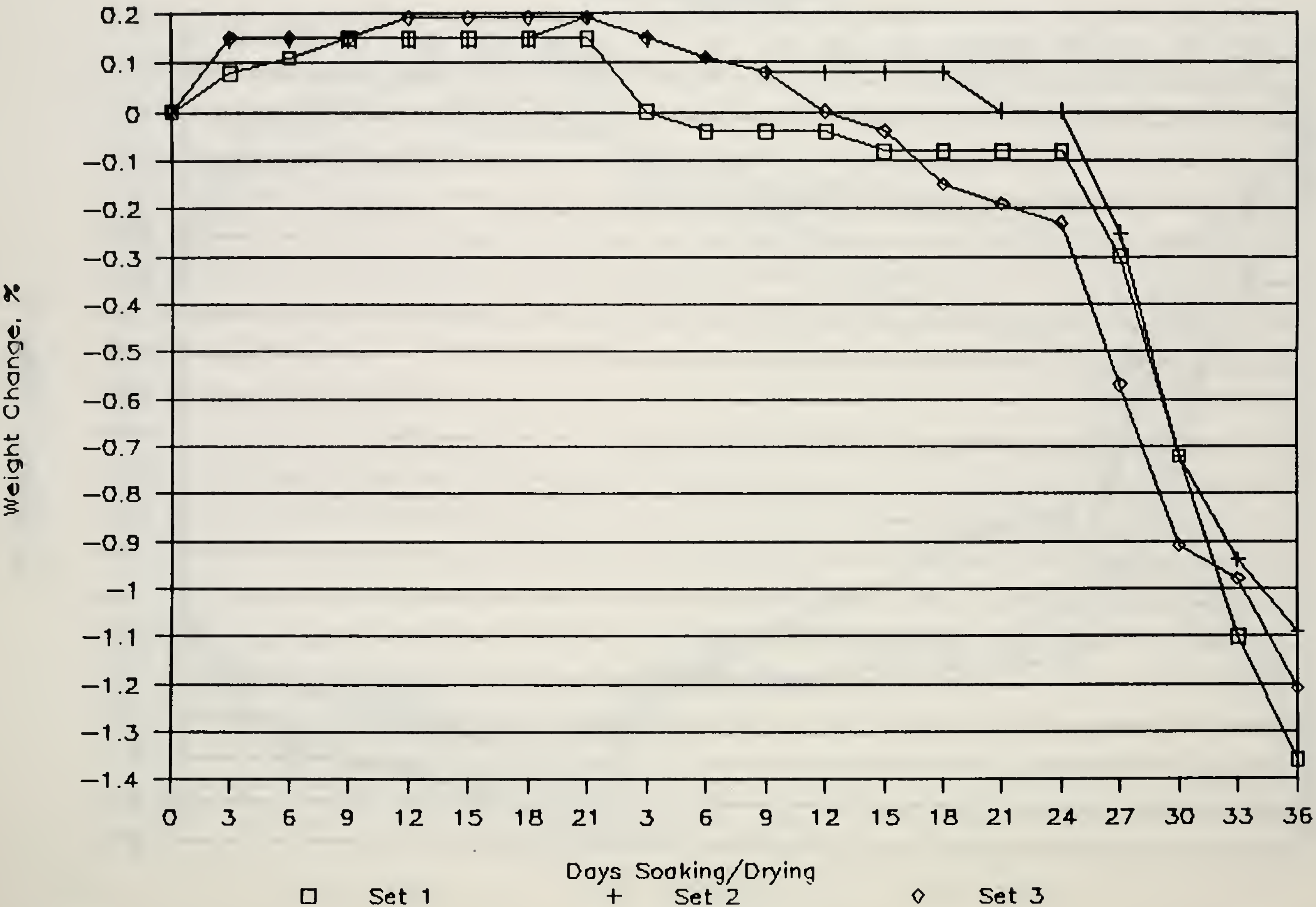

Figure C-18

Water Abs./Vapor Trans., Weight Change, Methyl Methacrylate - No. 12

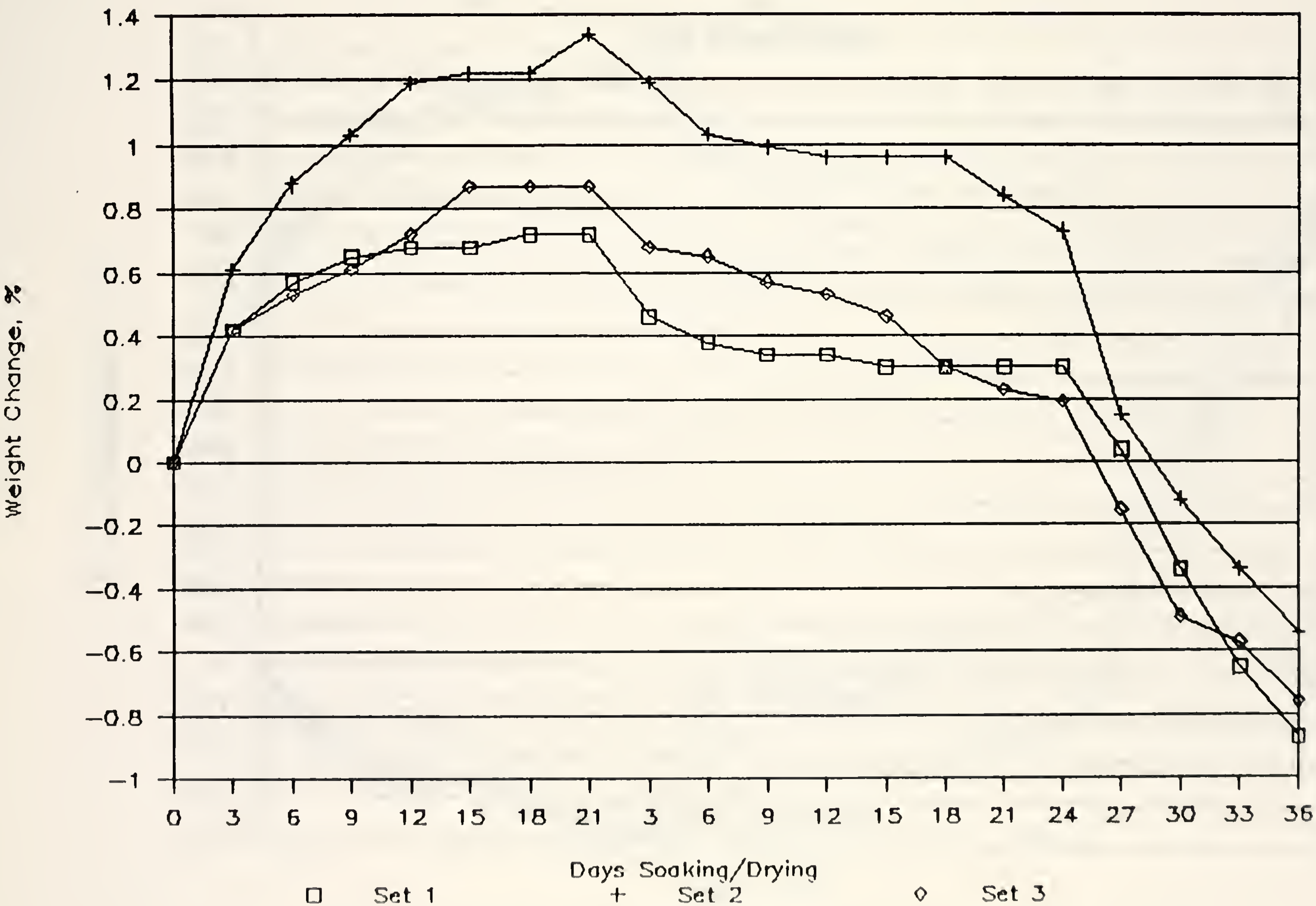

Figure C-19

Water Abs./Vapor Trans., Weight Change, Methyl Methacrylate - No. 13

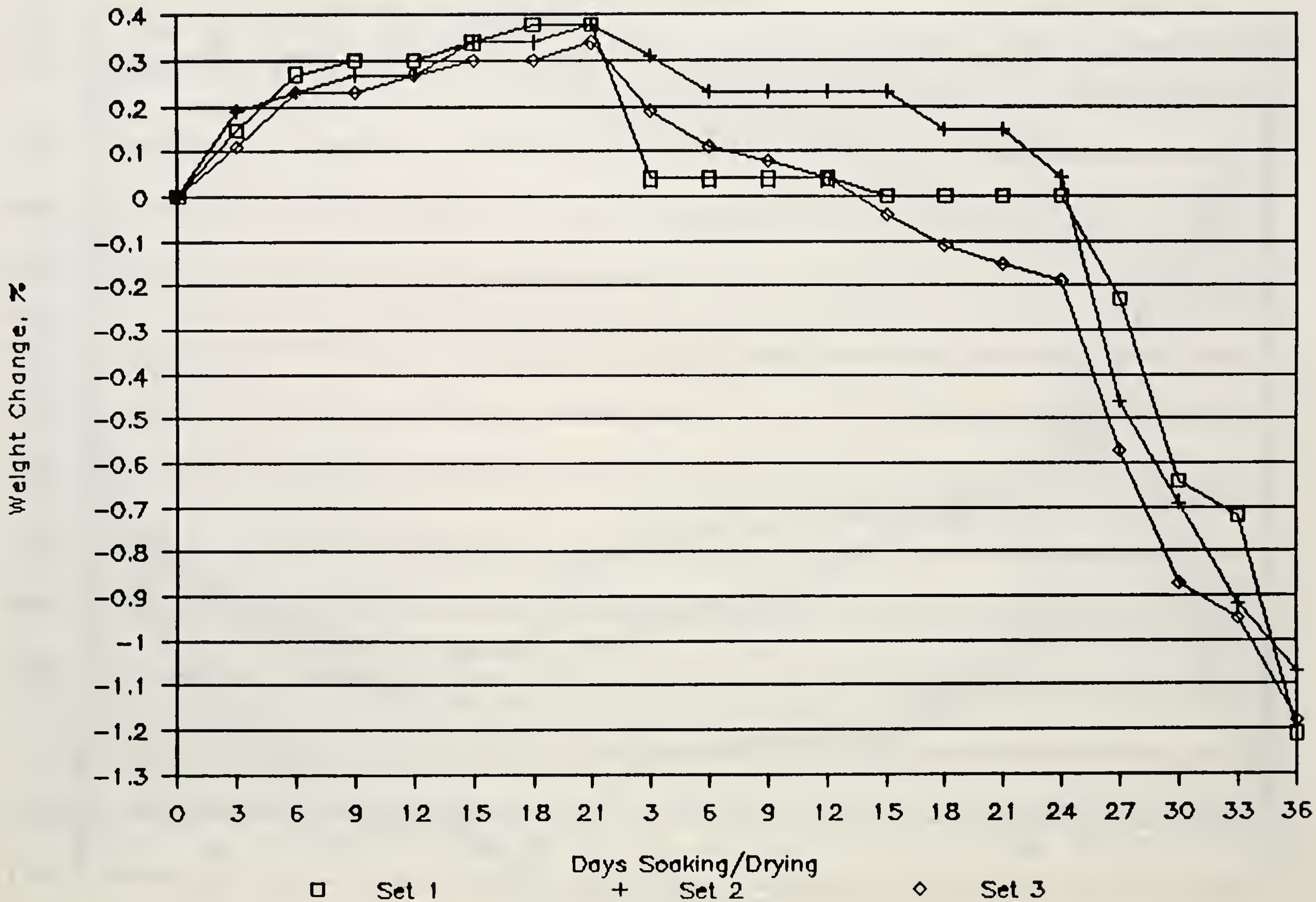

Figure C-20

Water Abs./Vapor Trans., Weight Change, Siloxane - No. 14

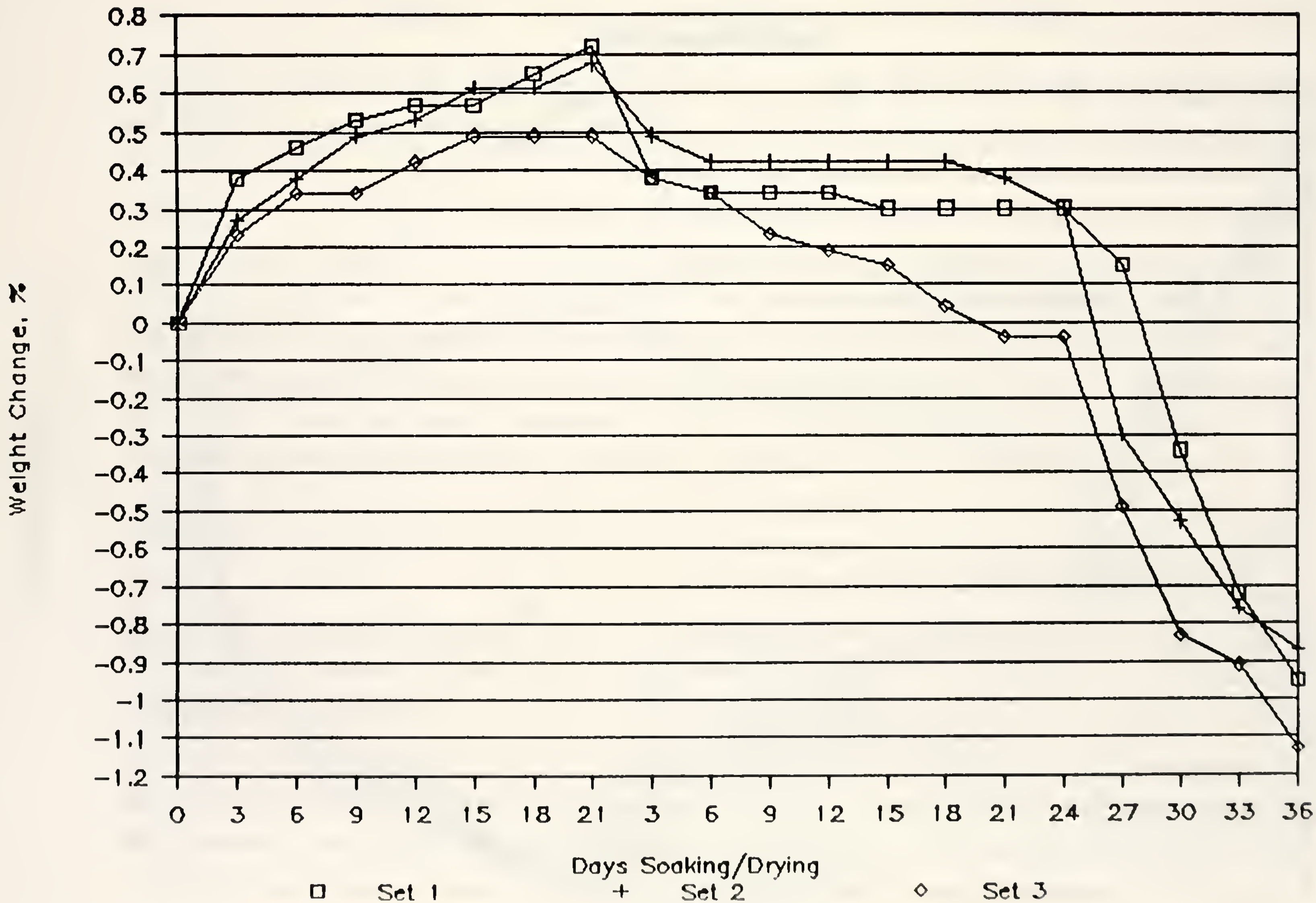

Figure C-21

Water Abs./Vapor Trans., Weight Change, Siloxane/Silicone - No. 15

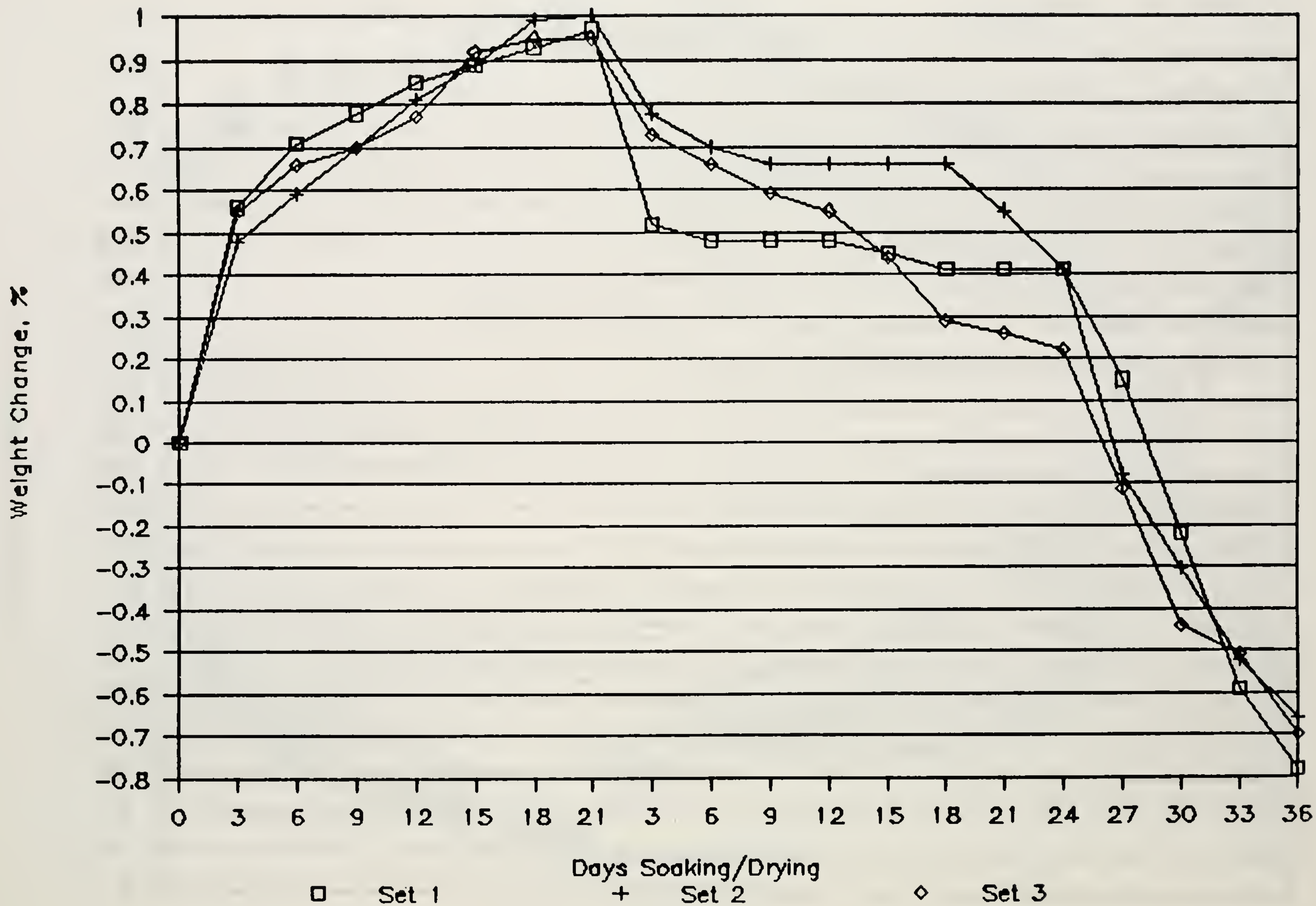

Figure C-22

Water Abs./Vapor Trans., Weight Change, Styrene Acrylic Copolymer - No. 16

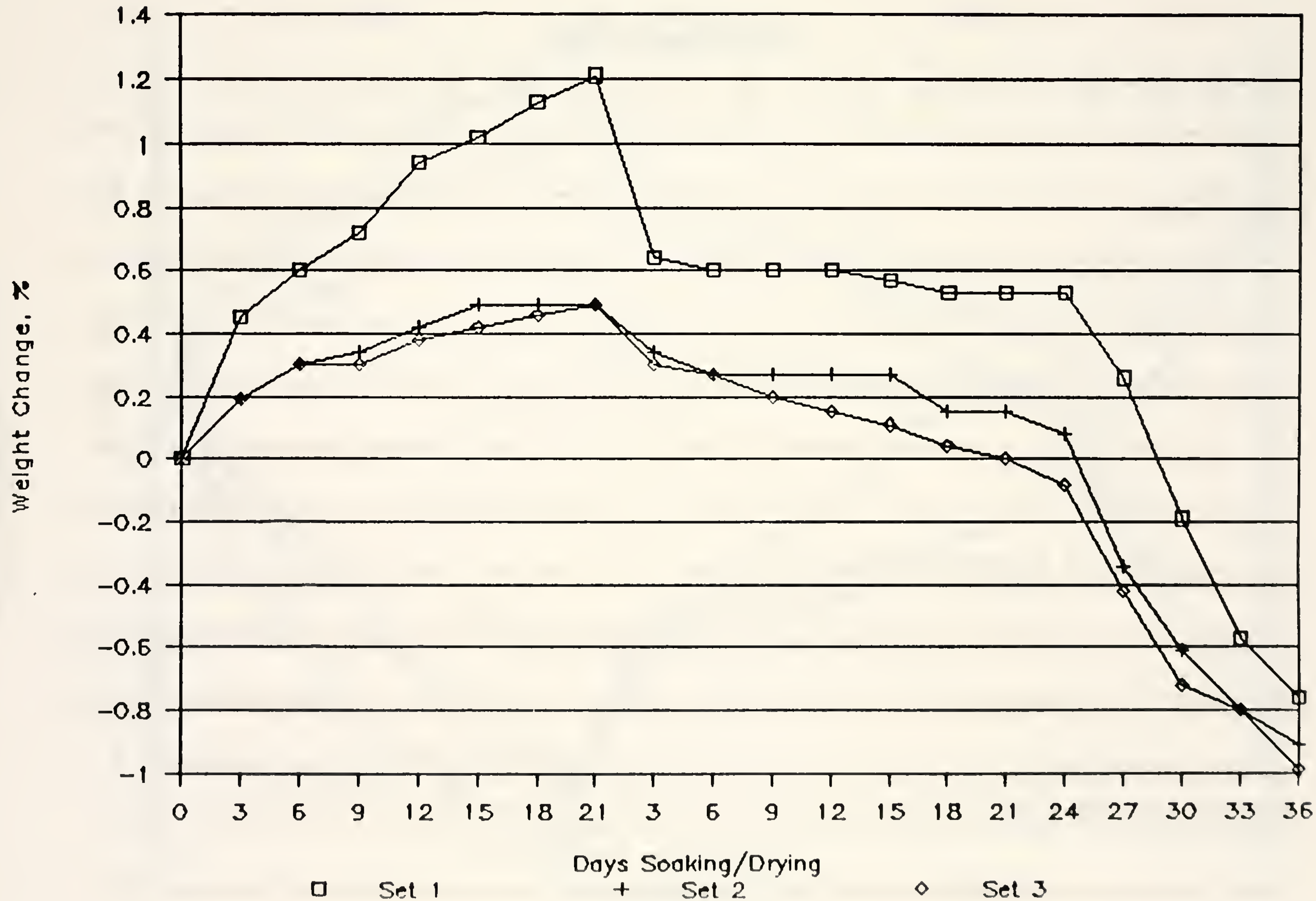

Figure C-23

Water Abs./Vapor Trans., Weight Change, Blend of Silanes - No. 18

Figure C-24

Water Abs./Vapor Trans., Weight Change, Vinyl Acrylic - No. 19

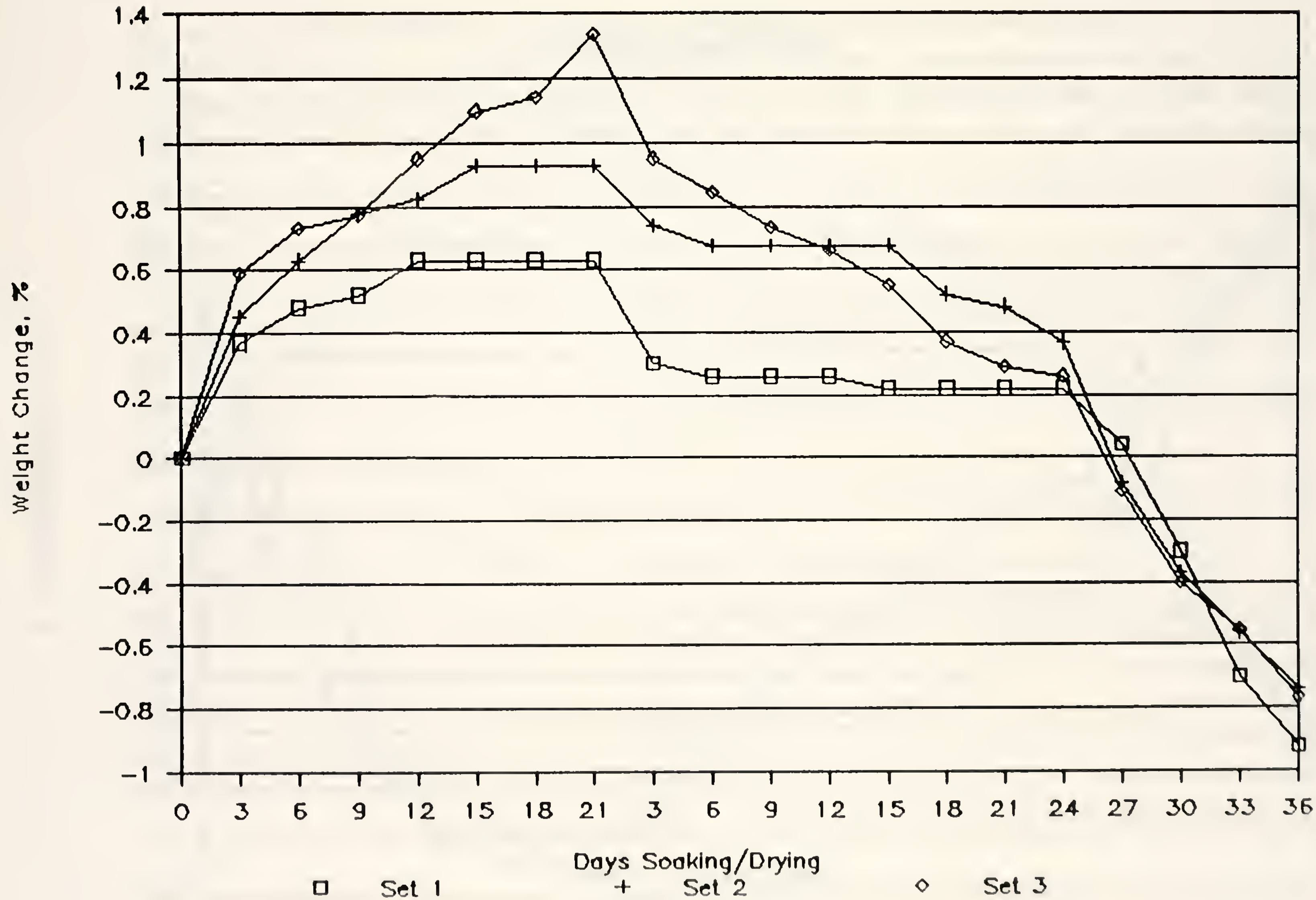

Figure C-25

Water Abs./Vapor Trans., Weight Change, Polyester Resin - No. 20

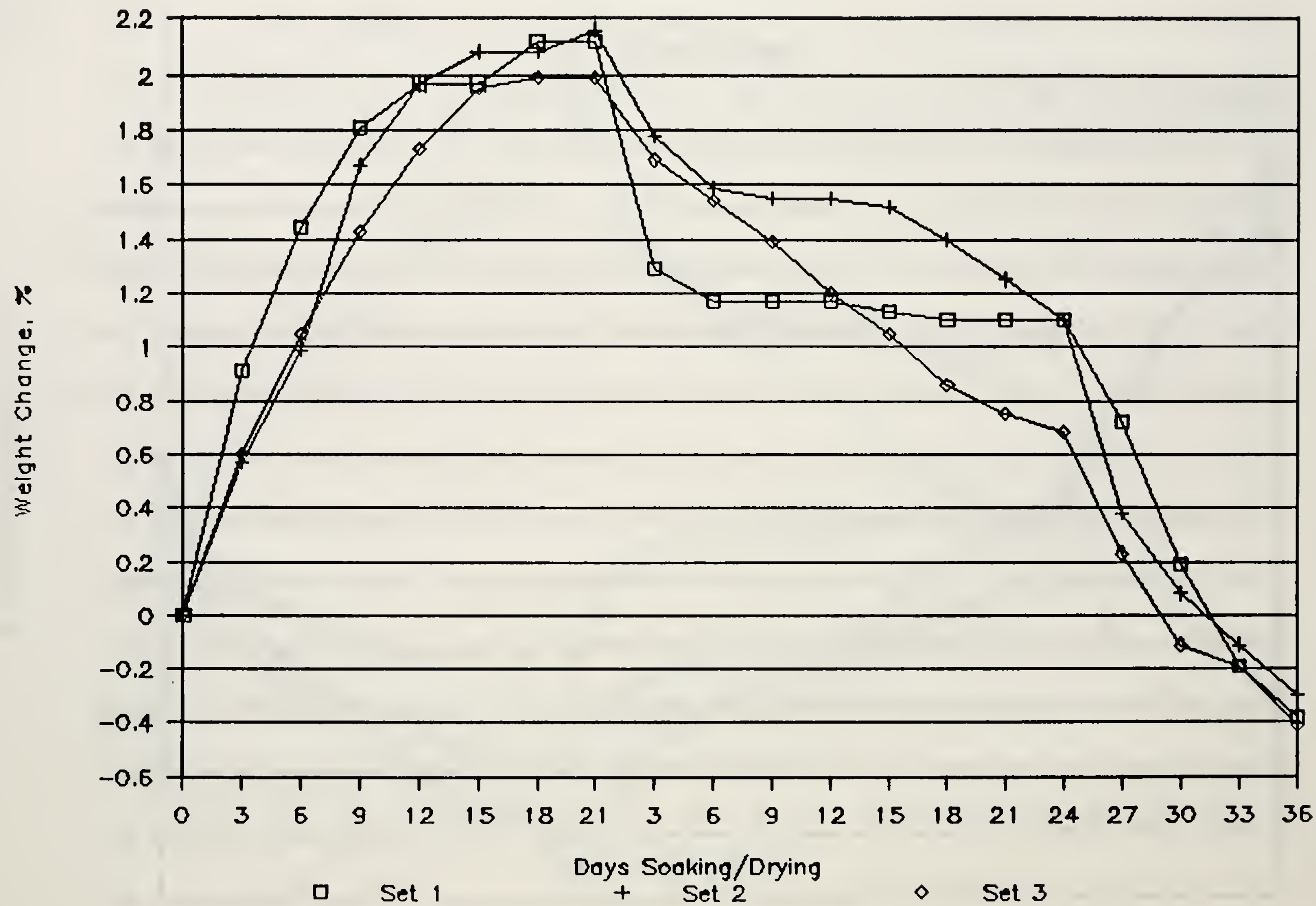

Figure C-26

Water Abs./Vapor Trans., Weight Change, Poly-Siloxane/Fumed-Silica - No. 21

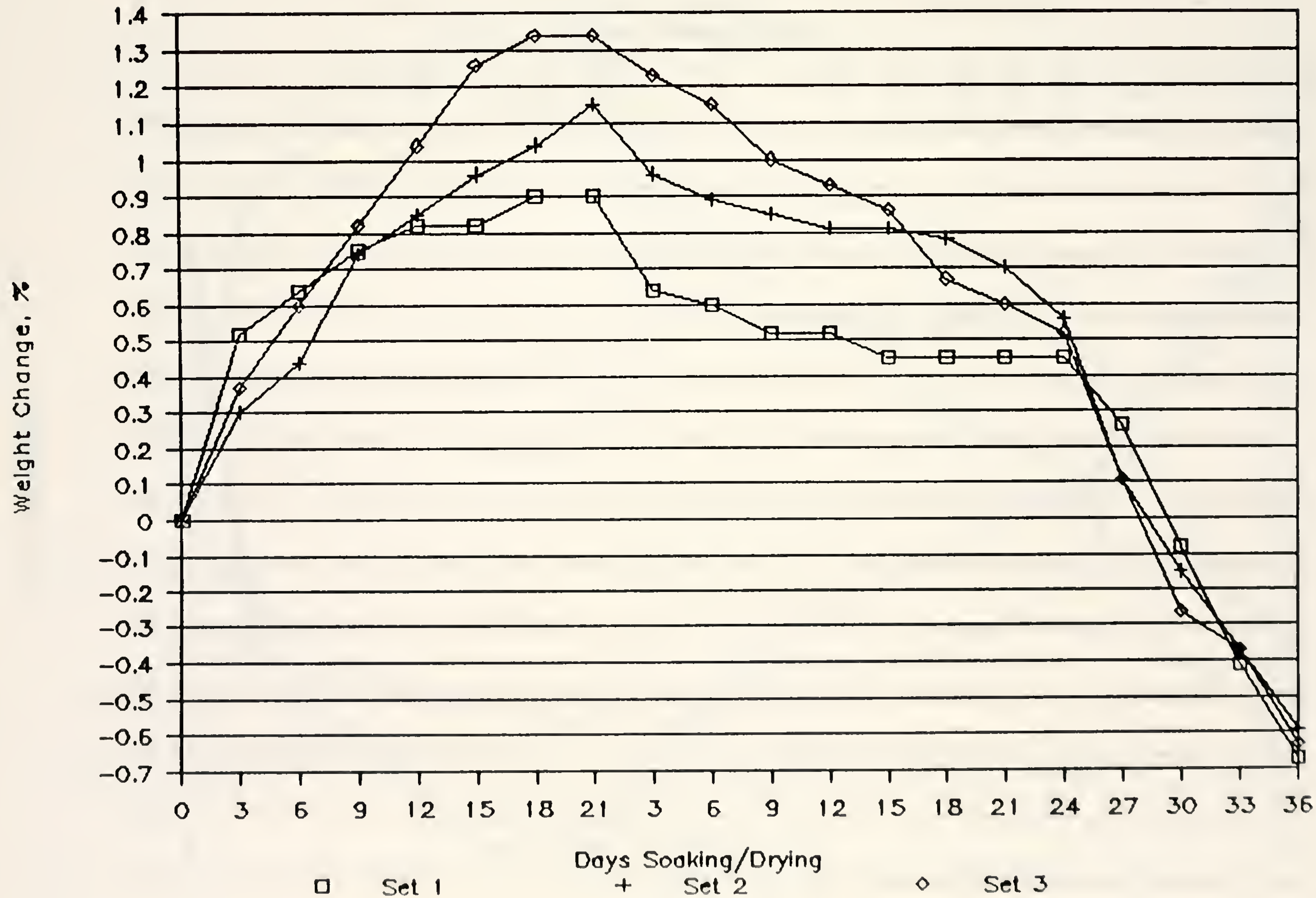

Figure C-27

Water Abs./Vapor Trans., Weight Change, Styrene Acrylic Copolymer - No. 22

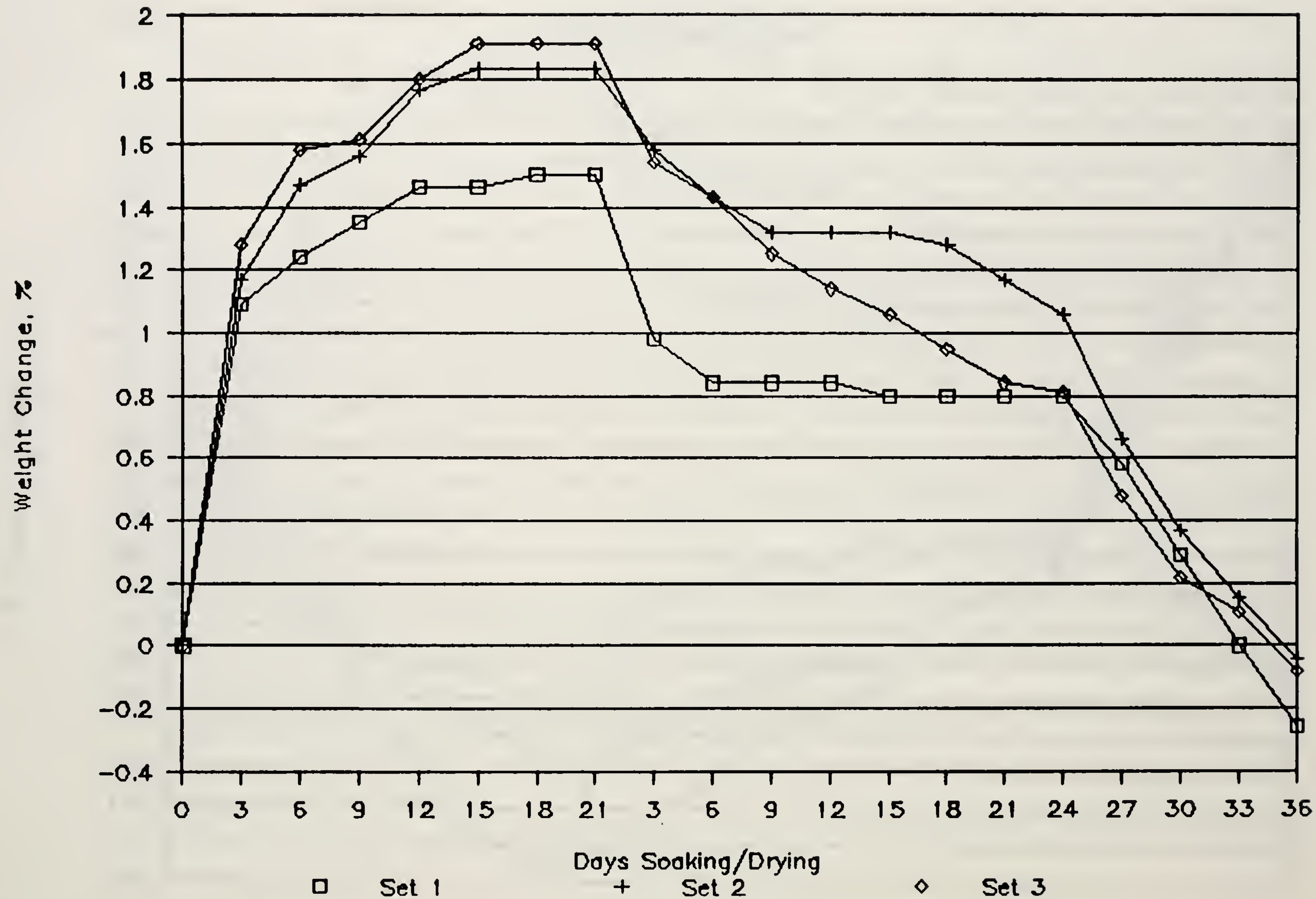

Figure C-28

Water Abs./Vapor Trans., Weight Change, Elastomeric Acrylic - No. 23

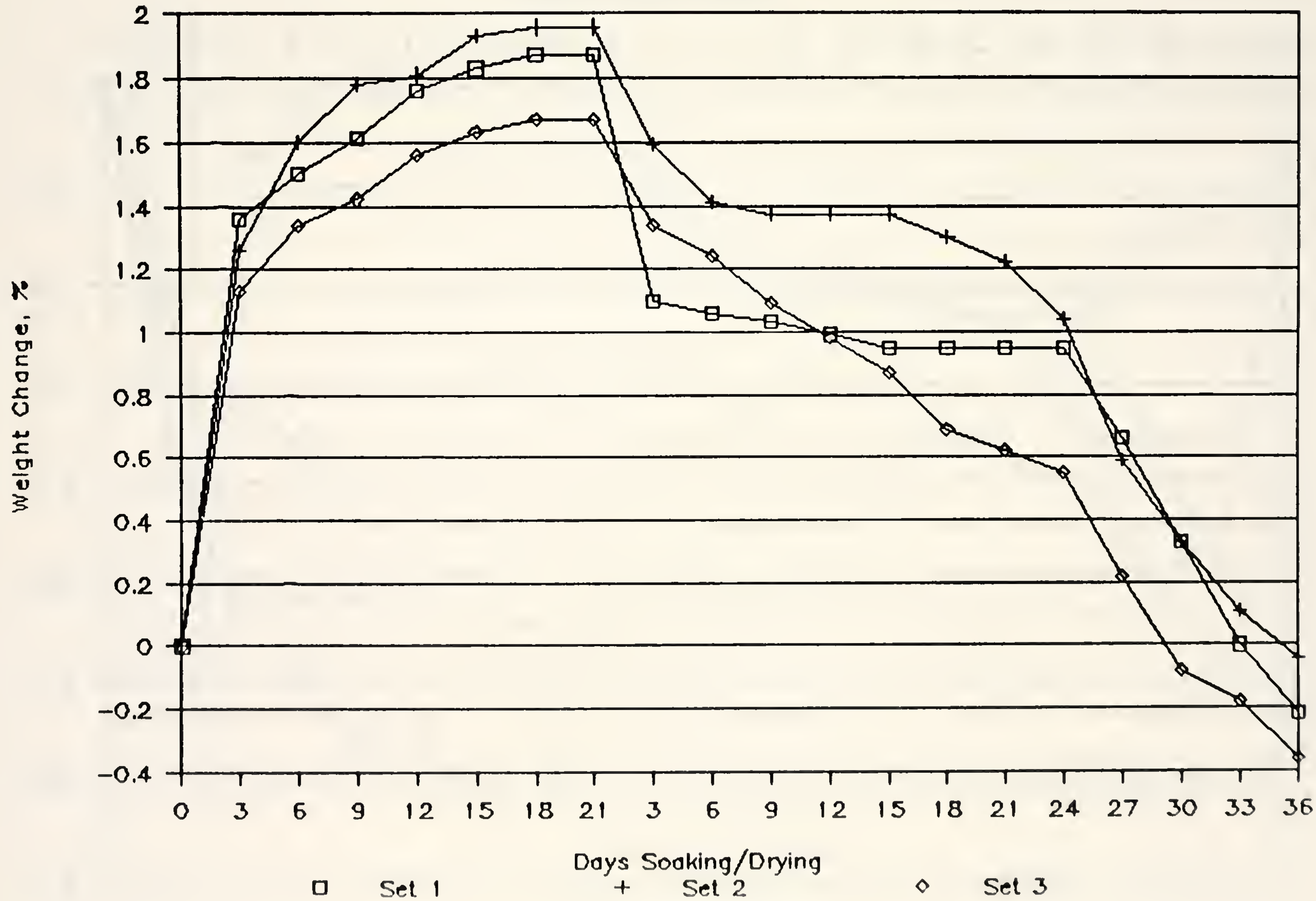

Figure C-29

Water Abs./Vapor Trans., Weight Change, Acrylic Resin - No. 24

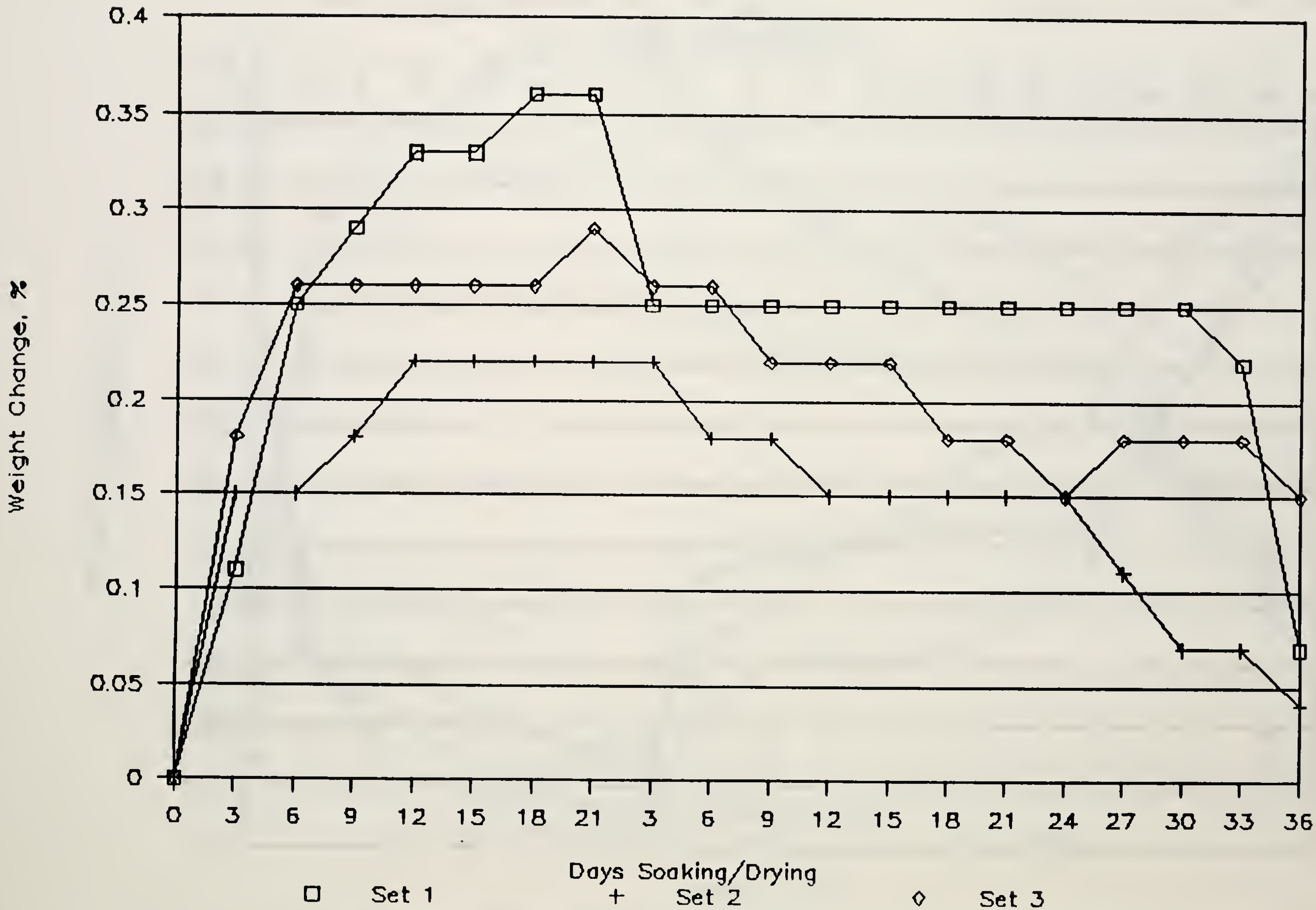

Figure C-30

Water Abs./Vapor Trans. Weight Change, Epoxy - No. 25

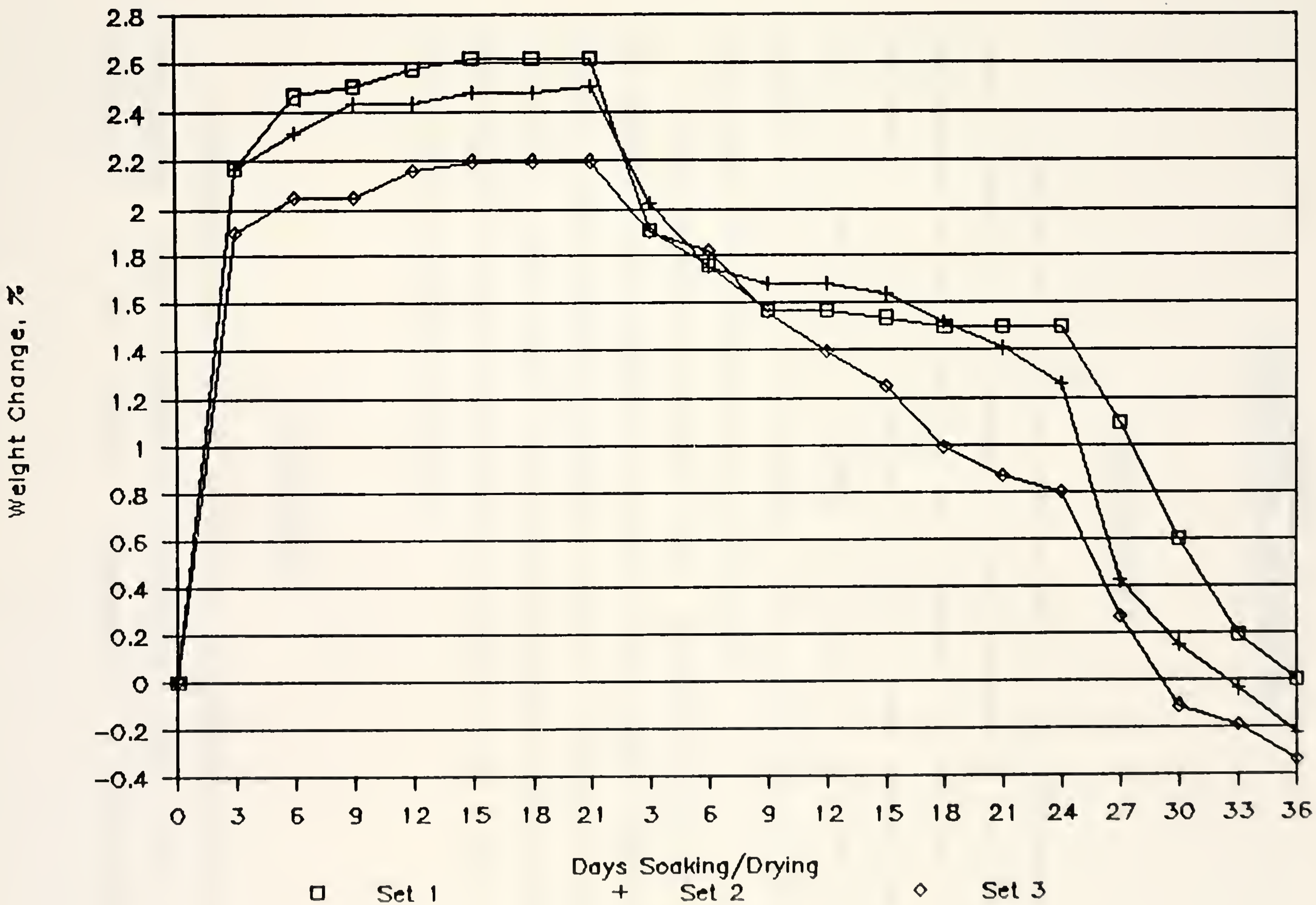

Figure C-31

Water Abs./Vapor Trans., Weight Change, Control

Appendix D
Accelerated Weathering

Test Objective

The objective of this test was to determine the influence of 24 weeks (6 months) of accelerated laboratory weathering tests on the performance of sealers/coatings when applied to concrete. The performance is judged by making periodical visual observations of the surface conditions, by measuring the chloride ion contents in the concrete at the end of the test period, and by measuring the gloss of the surface with a glossmeter every two weeks.

The accelerated weathering method that this study used was the northern climate method as desribed by the NCHRP Report No. 244 (11). This accelerated weathering cycle was designed to expose the slabs to a wide range of environmental conditions which included acid, saltwater, thermal heat, ultraviolet exposure, fresh water rinse, and overnight freezing and thawing.

Test Materials

Preliminary trial batches were made to determine the correct mix design. The mix design of the concrete was to meet the requirements of the Indiana Department of Transportation

specifications for Class A concrete (8). The test concrete was designed to have a w/c ratio no greater than 0.66, an air content of 5 to 8 percent, a ratio of fine aggregate to total aggregate between 35 and 45 percent (by weight), and a slump of approximately 3 in.

The significant properties of the concrete and its materials were as follows:

Portland cement	Type I
Air-entraining agent , ml	205
Cement content, lb	564
Fine aggregate, lb	1350
Coarse aggregate, lb	1850
Fine/Total aggregate, %	42.2
Water content, lb	312
Air content, %	6.2
W/C (by weight)	52.7
Slump, in.	2.75
28 days strength, psi	4530
Absorption of fines, %	1.56
Absorption of coarse, %	1.15

Sample Preparation

The concrete slabs were cast in wood frames that were coated with shellac for easy removal. The test slabs were 4 in. thick and 11 in. square. A dike about 1 in. high was formed on the test surface so that the saltwater could be ponded during testing.

The slabs were covered with a sheet of plastic and allowed to cure for one day in laboratory environment. After one day of curing, the slabs were stripped from their forms and transferred to a moisture curing room for 4 additional days. At the end of this curing period, the slabs were lightly sandblasted to remove the cement skin which normally wears off by natural weathering.

The slabs were then allowed to air dry in a laboratory environment for different lengths of time; ranging from age 7 to age 28. The sealers/coatings were applied using the manufacturer's recommendations. Nine samples were coated at the age of 7 days, 3 at the age of 14 days, 1 at the age of 21 days, and 11 at the age of 28 days. The amount of material for each slab was calculated using the weight of the material in lb per gallon, the recommended coverage rates, and the surface area of the slabs. This amount was applied by brush in a laboratory environment. The second coat, if necessary, was applied after 24 hours. The slabs were then stored in a laboratory environment for seven days.

Ultraviolet Light Apparatus

The monthly totals for normal ultraviolet radiation (with the wave lengths from 2950 to 3950 A') for winter months for Indianapolis is approximately 2460 watt-hours/sq meter/month (9). The ultraviolet source used during this phase of the testing consisted of standard 48 in. long, two two lamp fluorescent fixtures and 40 watt ultraviolet lamps (W-F40BL). The lamps operated at 430

milliamps, which provided 14 to 18 watts/sq meter since the lamps were positioned 9 in. above the slabs. Four slabs were positioned under two 48 in. long fixtures.

By using average values of monthly winter and summer ultraviolet radiation for northern regions, along with the average number of hours of daylight per month, 166.7 watt-hours/sq meter/day was calculated to be the approximate normal radiation from the sun for a typical yearly average day (10). This value was extracted from the NCHRP Report 244.

The test slabs received 3 hours per day for 5 weekdays and 66 hours per weekend of ultraviolet exposure. Thus, the slabs received approximately 1280 watt-hours/sq meter/week for the entire 24 week test period. The total cumulative ultraviolet light exposure during the 24 week testing was just over 30,000 watt-hours/sq meter, which is roughly equivalent to 185 yearly-average northern days of ultraviolet radiation exposure.

Northern Climate Test Procedure

This test method was based upon a daily cycle, with limited activity extending through the weekends. The following 24 hour cycle was repeated for the 5 weekdays for 24 weeks (11):

- 15 hour overnight freeze in air at 0 degrees F. The diked test surface was empty.

- 2 hour thaw in laboratory air at 73 to 83 degrees F. The diked test surface was empty.

- 3 hour exposure to ultraviolet radiation and thermal heat at 95 +/- 5 degrees F. The test surface was empty.

- 3 hour soaking period with 15 percent NaCl and 0.02 molar sulfurous acid water solution on the test surface (fresh solution every other day).

- Pour off test solution, rinse with fresh water, and drain.

- Return to freezer.

The specimens were exposed to the ultraviolet radiation and the 95 degrees F heat for the entire weekend. The diked test surface remained empty over the weekends.

The northern climate test solution contained a 15 percent NaCl and 0.02 molar sulfurous acid solution component to depict the salts that were spread over the highways throughout the winter and the acids found in the rains and atmosphere in northern industrial regions. This solution strength was used by PCA (12), WJE (13), and IDOH in previous accelerated weathering tests (6).

During the 24 week test period, visual inspections, photographs, and notes of the condition of the slabs were recorded bi-weekly. Glossmeter measurements were also taken to show the loss in gloss of the surfaces over the entire testing period using a 60 degree glossmeter.

Chloride Ion Content Procedure

Following the 24 week testing period, powder samples were taken from each of the 24 coated slabs and the untreated control

slabs. Two holes were drilled in each of the slabs in order to extract the powder samples. Each hole was first drilled to a depth of 1/2 in. Four powder samples were taken from both of the holes in each slab, giving us a total of eight samples from each slab. The first powder sample was taken at a depth of 1/2 in., the second at 1 in., the third at 1-1/2 in., and the fourth at 2 in. All eight of the powder samples were tested for chloride content and the two values obtained at each of the depths were averaged together. The total chloride content was determined using an acid-digestion, potentiometric titration procedure. This testing was done at the IDOH Materials and Testing lab with the help of their personnel.

Test Results and Observations

Visual Inspection of Surfaces

The test surface of each specimen was visually inspected bi-weekly throughout the testing period and at the conclusion of the test. The following tabulation describes the individual surface conditions:

Material No.	Surface Condition
Control	Uniform deep etching with many coarse aggregate showing.
1	Seventy percent of concrete surface slightly exposed concrete, yellowish-brown discoloration.

Material No.	Surface Condition
2	Epoxy surface deteriorated after eight weeks. Few coarse aggregate visible after 12 weeks of testing. Deep etch over 80 percent of surface with many coarse aggregate showing visible at end of test. Yellowish-brown color under remaining epoxy coating.
3	Epoxy coating deteriorated as soon as testing began. Light etch over 40 percent of surface after 10 to 12 weeks, few coarse aggregate visible. After 24 weeks, 60 percent of epoxy coating gone, deep etch of concrete surface with some coarse aggregate visible. Yellow-brown discoloration under remaining epoxy coating.
4	Glossy or shiny surface at start of test. Cloudy appearance under 20 percent of epoxy coating after just two weeks and 95 percent after only four weeks. Light etch on five percent of exposed concrete surface at the end of the test. Yellow-brown discoloration under the very thin layer of epoxy coating that remained.
5	Urethane surface totally intact with no concrete visible. No color change (still gray).
6	Forty-five percent of urethane coating flaked off after just two weeks, light etch with a few coarse aggregate visible. 90 percent of urethane coating totally flaked off after 24 weeks of testing. Uniform deep etch with many coarse aggregate showing. Same or worse appearance as the uncoated control specimen.
7	Uniform light etch with few coarse aggregate visible.

Material No.	Surface Condition
8	Uniform deep etch with many coarse aggregate showing, same or worse appearance as untreated control specimen.
9	Uniform light etch with few coarse aggregate visible.
10	Very light etch over concrete surface with no coarse aggregate visible.
11	Uniform light etch with few coarse aggregate visible.
12	Thirty-five percent of concrete surface exposed with light etch. Cloudy appearance under remaining coated surface.
13	Deterioration of coating immediately once the test began. Thirty percent of concrete surface exposed after 12 weeks, with light etching and a few coarse aggregate visible. Moderate etching on over 80 percent of surface with some coarse aggregate showing.
14	Uniform moderate etching with some coarse aggregate visible.
15	Forty percent of surface coating deteriorated after 12 weeks with light etching and some coarse aggregate visible. Uniform deep etching over the entire surface with many coarse aggregate showing at the end of the test, worse appearance than the control specimen.
16	After just two weeks, five percent of masonry coating flaked off. Forty percent of coating deteriorated after eight weeks with light etching on exposed concrete. After 16 weeks, 90 percent of coating flaked off with

Material No.	Surface Condition
16 cont.	moderate etching and few coarse aggregate visible. At the end of the testing period, 95 percent of the coating deteriorated, deep etching and some coarse aggregate showing. Slightly better appearance than control specimen.
18	Uniform deep etching with many coarse aggregate visible. Slightly better appearance than control specimen.
19	Masonry coating still intact with no concrete visible. No change in the original color (white).
20	Masonry coating still intact with no concrete visible. No discoloration from original off-white color.
21	Uniform moderate etching with some coarse aggregate showing. Better appearance than control specimen.
22	Five percent of coating flaked off with light etching in exposed area. No discoloration from original white.
23	Masonry coating still intact with no concrete visible. No discoloration from original white.
24	Masonry coating still intact with no concrete visible. No discoloration from original white.
25	Epoxy coating still intact with no concrete visible. Original gray color changed to a greenish-brown color.

Glossmeter Data and Results

The glossiness of the test surfaces is one of indexes to the overall appearance of the concrete and can be measured with a glossmeter. This device uses a 60 degree angle of reflection to measure the gloss on a surface. The measured values are dependent on a number of factors, such as: the smoothness and gloss of the surface coating, the levelness of the concrete surface, and the amount, if any, of water on the surface. The test surface of the samples was the largest deterring factor, because all of the samples' test surfaces were quite uneven. The glossmeter only read to one decimal, so consequently the accuracy of the device was somewhat limited. Due to the above mentioned factors, four readings were taken on each surface every two weeks and then averaged to obtain a mean value for that particular day. The average glossmeter readings for Weeks 0 to 24 can be found in Table D-1. At the end of this Appendix, Figures D-16 through D-25 graphically display the glossmeter results vs. time for each generic type.

The following subsections will discuss the results found in Table D-1 by generic type.

Epoxies. The glossmeter values of all five of the epoxy formulations decreased from Week 0 to Week 24. Most of the decreases occurred within the first four to eight weeks of testing. The most significant decrease was found with No. 25 (100% solids). Its gloss dropped from 14.2 to 4.33 after only four and all the way down to 0.73 by the end of the test. The next largest drop occur with No. 4 (50 % solids), 9.53 to 0.48, most of which occurred within the first eight weeks

Table D-1

Glossmeter Readings - Weeks 0 to 24

Sample Number	Generic Type (Solids)	Week 0	2	4	6	8	10	12	14	16	18	20	22	24
1	Epoxy (50%)	5.95	3.85	2.50	2.20	1.48	1.46	1.38	1.29	1.24	1.19	1.18	1.20	0.78
2	Epoxy (20%)	0.75	0.75	0.80	0.28	0.23	0.20	0.13	0.03	0.00	0.00	0.00	0.05	0.02
3	Epoxy (50%)	1.55	0.60	0.53	0.23	0.10	0.08	0.05	0.00	0.05	0.05	0.05	0.10	0.08
4	Epoxy (50%)	9.53	5.43	2.63	1.48	0.60	0.48	0.48	0.45	0.50	0.52	0.45	0.52	0.48
5	Urethane (55%)	3.93	3.75	3.63	2.58	2.35	2.31	2.24	2.25	2.23	2.08	2.02	1.93	1.85
6	Urethane (30%)	1.90	1.33	0.88	0.63	0.30	0.13	0.00	0.18	0.03	0.03	0.00	0.13	0.10
7	Silane (40%)	0.23	0.23	0.40	0.40	0.23	0.20	0.10	0.08	0.12	0.08	0.05	0.15	0.08
8	Silane (<20%)	0.25	0.18	0.30	0.22	0.13	0.20	0.03	0.05	0.00	0.10	0.00	0.15	0.00
9	Silane (20%)	0.13	0.33	0.20	0.20	0.20	0.18	0.10	0.10	0.10	0.13	0.15	0.15	0.13
10	Silane (40%)	0.23	0.28	0.25	0.25	0.25	0.20	0.25	0.43	0.38	0.31	0.20	0.25	0.23
11	Silicone (5%)	0.15	0.23	0.20	0.15	0.20	0.20	0.23	0.25	0.25	0.38	0.23	0.05	0.03
12	Methyl Meth-acrylate (20%)	4.15	3.78	1.98	1.68	1.90	1.88	1.63	1.83	2.20	2.08	1.58	1.52	1.50
13	Methyl Meth-acrylate (30%)	1.88	1.60	0.85	0.95	0.88	0.90	0.45	0.43	0.20	0.35	0.55	0.30	0.28
14	Siloxane (20%)	0.73	0.70	0.30	0.13	0.25	0.23	0.00	0.00	0.03	0.05	0.10	0.15	0.10
15	Siloxane/ Silicone (10%)	0.53	0.65	0.55	0.50	0.53	0.65	0.13	0.00	0.00	0.00	0.00	0.02	0.00
16	Styrene/Acrylic Copolymer (75%)	0.58	0.83	0.70	0.05	0.05	0.08	0.03	0.00	0.05	0.00	0.00	0.05	0.00
18	Blend of Silanes (30%)	0.25	0.33	0.33	0.23	0.25	0.23	0.15	0.28	0.08	0.08	0.13	0.05	0.05
19	Vinyl Acrylic (58%)	1.35	1.35	1.28	1.13	1.13	1.10	1.03	1.15	0.95	0.90	1.15	1.25	1.15
20	Polyester Resin (60%)	0.30	0.30	0.15	0.20	0.10	0.05	0.05	0.05	0.08	0.03	0.03	0.02	0.03
21	Poly-siloxane/ Silica (7%)	0.55	0.68	0.53	0.58	0.53	0.43	0.30	0.15	0.05	0.00	0.08	0.05	0.00
22	Styrene/Acrylic Copolymer (61%)	1.55	1.63	1.55	1.50	1.43	1.38	1.38	1.33	1.20	0.98	1.15	1.05	1.05
23	Elastomeric Acyrlic	1.20	1.10	0.98	0.93	0.88	0.90	0.88	1.08	0.85	1.35	0.93	1.13	0.93
24	Acyrlic Resin	0.88	0.93	0.85	0.75	0.73	0.70	0.70	0.68	0.65	0.83	0.60	0.90	0.70
25	Epoxy (100%)	14.20	11.50	4.33	2.75	2.70	1.55	1.35	1.28	1.20	1.15	1.06	0.95	0.73
Control	----	0.20	0.25	0.15	0.13	0.10	0.05	0.03	0.00	0.00	0.00	0.00	0.03	0.00

(9.53 to 0.6). Sample No. 1 (50 % solids) experienced a decrease from 5.95 to 0.78. Samples No. 2 (20 % solids) and No. 3 (50 % solids) gloss only dropped a little, partly due to the fact that they didn't have too far to drop in the first place; 0.75 to 0.02 and 1.55 to 0.08, respectively.

Urethanes. The glossmeter values from Sample No. 5 (55 % solids) dropped from 3.93 to 1.85. This was the highest glossmeter value of all of the samples at the conclusion of this test. Sample No. 6 (30 % solids) did not perform as well as the other urethane. Its values decreased from 1.90 to 0.30 after just eight weeks and finally down to 0.1.

Silanes. Due to the fact that this particular generic type is a classified as a penetrant, the glossmeter values couldn't really reflect the gloss of the surface coating with a 60 degree glossmeter. As a result of this fact, the values obtained from these next few samples are actually the gloss of the surface of the concrete and the ability of the penetrant to resist the deterioration of that surface. All four of the silanes were quite consistent in their ability to resist the deterioration of the concrete surface. The glossmeter values of Samples No. 7, No. 9, and No. 10 stayed right around 0.25 to 0.10 throughout the entire test period, while the values of Sample No. 8 decreased from 0.25 to 0.

Silicone. The glossmeter values for Sample No. 11 (5 % solids) varied from 0.15 up to 0.38 and finally down to 0.03. This material is classified as a penetrant.

Methyl Methacrylates. The glossmeter values for Sample No. 12

decreased from 4.15 to 1.50. The majority of the loss was in the first four weeks, where the gloss decreased from 4.15 to 1.98. The glossmeter values of Sample No. 13 (30 % solids) decreased from 1.88 to 0.28.

Siloxane. Sample No. 14 (20 % solids) is classified as penetrant and its glossmeter values decreased from 0.73 to 0.10. The values dropped to 0.00 after 12 weeks and from then until the end of the test, the values varied from 0.00 to 0.15.

Siloxane/Silicone. This material, No. 15, is also classified as a penetrant. Its glossmeter values decreased from 0.53 to 0.0 after 14 weeks and stayed there throughout the remainder of the test period.

Blend of Silanes. Sample No. 18, a blend of silanes with 30 % solids, is classified as a penetrant and its glossmeter values varied from 0.33 down to 0.05.

Poly-Siloxane/Fumed Silica. This material, No. 21, is classified as a penetrant with a solids content of 7 percent. Its glossmeter values decreased from 0.55 to 0.00.

Masonry Coatings. The glossmeter values of Sample No. 16, a styrene/acrylic copolymer with 75 % solids content, decreased from 0.58 to 0.05 after just six weeks and varied from 0.08 to 0.00 for the remainder of the 24 weeks. Another styrene/acrylic copolymer, Sample No. 22 (61 % solids) saw its gloss values decrease steadily from 1.55 down to 1.05.

The glossmeter values of Sample No. 19, a vinyl acrylic with 58 % solids, remained relatively constant over the entire test period, fluctuating from 1.35 down to 0.95 and finally ending at 1.15. The

polyester resin, Sample No. 20 (60 % solids), experienced a decrease in the its glossmeter values from 0.30 down to 0.03.

The glossmeter values of Sample No. 23, an elastomeric acrylic, remained fairly constant varying from 1.20 to 0.93. The glossmeter characteristics of Sample No. 24, the acrylic resin, were quite consistent also. Its values varied from 0.88 at the start, up to 0.93, down to 0.60, and finally ending at 0.70.

The control specimen's glossmeter values started at 0.20 and dropped to 0.00 after 14 weeks and remained there for the remainder of the test period.

Chloride Titration Results

The average percent chloride content ranging between a depth of 0.5 in. and 2.0 in. for all of the materials can be found in Table D-2 and D-3 and are graphically displayed in Figure D-1. This table also gives the overall rank of each material. All of the individual chloride titration data can be found in Table D-4 of this appendix. Also in this Appendix are graphs displaying each generic type's percent chloride vs. depth (Figures D-2 through D-5). This appendix contains graphs of chloride titration values vs. depth for each generic type in Figures D-6 through D-15.

The following subsections discuss the average percent chloride content values found in Table D-2 and D-3 and Figure D-1.

Table D-2

Average Percent Chloride Titration Values- Ponding Slabs

Sample Number	Generic Type (% solids)	Average % Chloride	Percent Reduction
1	Epoxy (50%)	0.0750	82.26
2	Epoxy (20%)	0.4075	3.64
3	Epoxy (50%)	0.0554	86.91
4	Epoxy (50%)	0.1245	70.56
5	Urethane (55%)	0.1363	67.78
6	Urethane (30%)	0.2953	30.18
7	Silane (40%)	0.0376	91.11
8	Silane (<20%)	0.0349	91.75
9	Silane (20%)	0.0496	88.26
10	Silane (40%)	0.0295	93.02
11	Silicone (5%)	0.0444	89.51
12	Methyl Methacrylate (20%)	0.2306	45.46
13	Methyl Methacrylate (30%)	0.4099	3.08
14	Siloxane (20%)	0.0415	90.19
15	Siloxane/Silicone (10%)	0.2940	30.48
16	Styrene/Acrylic Copolymer (75%)	0.4822	-14.03
18	Blend of Silanes (30%)	0.0319	92.46
19	Vinyl Acrylic (58%)	0.2861	32.34
20	Polyester Resin (60%)	0.2894	31.57
21	Poly-Siloxane/Silica (7%)	0.0814	80.76
22	Styrene/Acrylic Copolymer (61%)	0.5280	-24.86
23	Elastomeric Acrylic	0.2923	30.89
24	Acyrlic Resin	0.3480	17.71
25	Epoxy (100%)	0.0449	89.39
CONTROL	-----	0.4229	-----

Table D-3

Ponding Slab Chloride Titration Results

Sample Number	Average Percent Chloride Depth, in. 0.50	1.00	1.50	2.00	Average
1	0.1825	0.0460	0.0385	0.0330	0.0750
2	1.1795	0.2480	0.0565	0.1460	0.4075
3	0.1275	0.0525	0.0195	0.0220	0.0554
4	0.3675	0.0595	0.0315	0.0395	0.1245
5	0.3630	0.1425	0.0195	0.0200	0.1363
6	0.8515	0.2750	0.0355	0.0190	0.2953
7	0.0715	0.0230	0.0220	0.0340	0.0376
8	0.0700	0.0235	0.0190	0.0270	0.0349
9	0.0705	0.0400	0.0195	0.0685	0.0496
10	0.0440	0.0265	0.0185	0.0290	0.0295
11	0.0675	0.0250	0.0225	0.0625	0.0444
12	0.5900	0.2610	0.0475	0.0240	0.2306
13	1.0365	0.5005	0.0670	0.0355	0.4099
14	0.0760	0.0300	0.0240	0.0360	0.0415
15	0.5979	0.3665	0.1675	0.0440	0.2940
16	0.9758	0.6895	0.1840	0.0795	0.4822
18	0.0525	0.0305	0.0215	0.0230	0.0319
19	0.7805	0.2865	0.0400	0.0375	0.2861
20	0.6545	0.2945	0.1515	0.0570	0.2894
21	0.2250	0.0515	0.0205	0.0285	0.0814
22	1.0680	0.6540	0.2900	0.1000	0.5280
23	0.6425	0.4070	0.0940	0.0255	0.2923
24	0.7965	0.4300	0.1090	0.0565	0.3480
25	0.0785	0.0395	0.0300	0.0315	0.0449
Control	0.9615	0.6080	0.0945	0.0275	0.4229

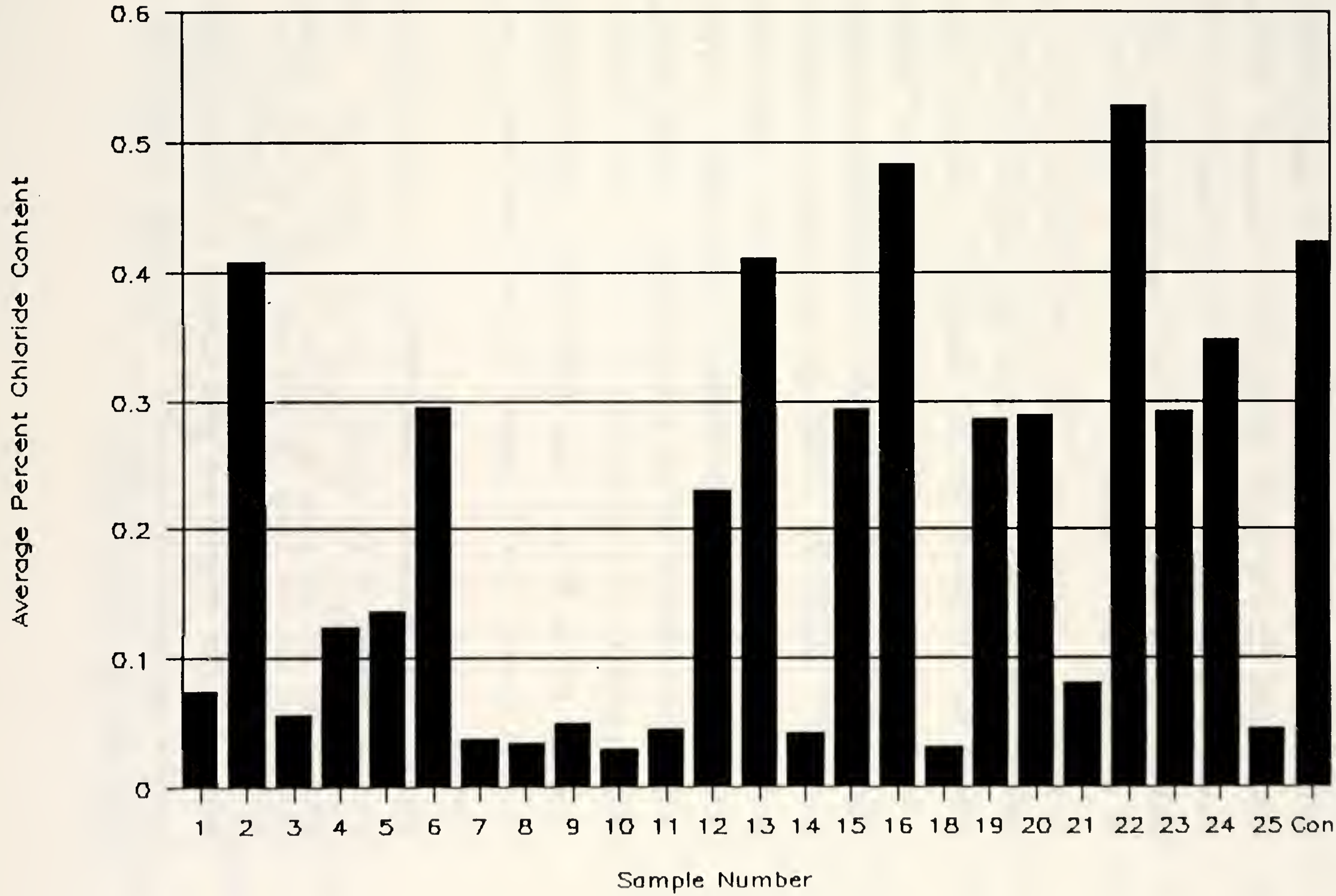

Figure D-1

Average Percent Chloride Content per Sample
Accelerated Weathering Titration

Epoxies. Four out of five of the epoxy formulations performed quite well in resisting the intrusion of chloride ions, ranging from 89.39 percent (No. 25) to 70.56 percent (No. 4) reduction of chlorides compared to the control. The other epoxy, labeled No. 2 had an percent chloride content reduction that was just slightly above that of the control at 3.64 percent.

Urethanes. Material No. 5 was 13th overall and had an average percent chloride content of approximately one-third of the control. Sample No. 6, however, was less ineffective at resisting chloride ion penetration just over 30 percent better than the control specimen.

Silanes. This generic type was one of the most effective chloride ion resistors. Sample No. 10 was the most effective overall with an average chloride content of just below 0.03 percent (percent reduction of chlorides 93% compared to the control). The other three silanes percent chloride content ranged from 91.75 down to 88.26 compared to the control.

Silicone. Silicone finished sixth overall with a reduction of chlorides of 89.51 percent. This is roughly 10 times more effective than the control.

Methyl Methacrylates. Sample No. 12 was 14th overall and had about 55 percent of the chlorides that the control had. Material labeled No. 13 was about as effective as the control specimen in resisting the penetration of chloride ions (3.07% reduction).

Siloxane. This material was quite effective in resisting chloride ion intrusion and finished fifth overall. This sample performed 10 times better than the control specimen.

Siloxane/Silicone. This combination of materials was fairly ineffective in resisting chloride penetration and finished 18th. Sample No. 15 had approximately 70 percent of the chlorides that the control specimen had.

Blend of Silanes. This sample was the second best material in resisting chloride ion penetration. It reduced the chlorides by over 92 percent compared to the control.

Poly-Siloxane/Fumed Silica. This material had only 20 percent of the chlorides compared to the control specimen but was 11th compared to the rest of the materials.

Masonry Coatings. This generic type as a whole was the least effective of all of the generic types. Both of the masonry coatings based on a styrene/acrylic copolymer had higher average percent chloride contents than the control specimen (ranging from 14 to 25 percent more). When compared to the control, the other four materials had chloride content reductions ranging from 32.34 percent down to 17.71 percent.

Potential Sources of Errors

- The slabs were unable to be cured in a lime-saturated solution for the four days after the inital one day curing because of unlimited facilites. Instead they were cured in a 100% RH moisture room for the same amount of time.

- The slabs were over sandblasted which left a very porous

surface. This reduced the ability of many of the sealers/coatings to properly seal the surface without having to apply additional coatings. The surface of the concrete slabs were not perfectly level and therefore created different thicknesses of the coatings (usually at the edges).

- The acid strength (0.02M) of the solution that was ponded on the surface of the slabs was too strong and caused excessive deterioration to the surface coatings/sealers.

- The glossmeter only had the ability to measure the gloss of the concrete slab surface to the nearest 0.01. This may have forced the results to be rounded off and the level of accuracy to decrease.

Conclusions

The test results from the accelerated weathering tests lead to the following conclusions and observations:

1. Epoxies. All five of the epoxy formulations experienced a significant decrease in their gloss from the start of the testing to the end. The number of coats and the solids content had a direct relation to the performance of these materials. The two epoxies that required only one coat exhibited deep etching and of these two, the one with the higher solids content resisted chloride penetration much better; while the two epoxies that required two coats experienced only very light etching and were quite effective against chloride intrusion. The epoxy with 100 percent solids demonstrated no deterioration, did discolor some, and resisted chloride intrusion very effectively.

2. Urethanes. The urethane with the 55 percent solids performed better in every aspect than the urethane with only 30 percent solids. The former remained totally intact with the concrete surface, retained a large percentage of its gloss, and had one-third the chlorides of the control specimen. The latter urethane flaked off over 90 percent of the surface and exhibited uniform deep etching.

3. Silanes. This generic type was the most effective material against chloride intrusion. All of the silanes exhibited very light etching on the surface, except for No. 8 that displayed deep etching. Since this generic type is classified as a penetrant and not a coating, the gloss of these materials stayed relatively constant throughout the entire test period, because it was a measure of the gloss of the concrete itself.

4. Silicone. This material is also a penetrant, so therefore the measured glossmeter values remained relatively constant. It was a very effective screen against chloride ion penetration, however there was light etching on the concrete surface.

5. Methyl Methacrylates. Both of these materials exhibited visible deterioration with light to moderate etching and a decrease in their gloss at the conclusion of the testing. These two materials demonstrated average to below average effectiveness in resisting chloride ion intrusion. The "better" of the two was the product that had a silane primer.

6. Siloxane. This material's gloss decreased to nearly nothing and had uniform moderate etching on the concrete surface. It was, however, 10 times more effective against chloride ion penetration

than the control.

7. Siloxane/Silicone. This material was ineffective against deterioration, chloride ion penetration, and maintaining its gloss. The concrete surface was very similar in appearance at the end of the test to that of the control specimen.

8. Blend of Silanes. This material is classified as a penetrant. The gloss remained relatively constant but there was uniform deep etching over the concrete surface. This material was, however, extremely effective in resisting chloride ion intrusion.

9. Poly-Siloxane/Fumed Silica. This material exhibited moderate etching and a decrease in its gloss. It was 80 percent effective as a chloride ion screen.

10. Masonry Coatings. The appearance of four out of the six masonry coatings remained fairly constant along with their glossmeter values. The two products that were based on a styrene/acrylic copolymer were the only ones to exhibit any surface deterioration. Sample No. 22 experienced a flaking off of five percent of its coating at the end of the test, while No. 16's concrete surface was 95 percent exposed with uniform deep etching. The control specimen was more effective as a chloride ion screen than either No. 22 or No. 16. The other four masonry coatings were only slightly better in resisting chlorides than the control. As a whole, the masonry coatings were ineffective chloride screens, but were able to, for the most part, maintain their appearance.

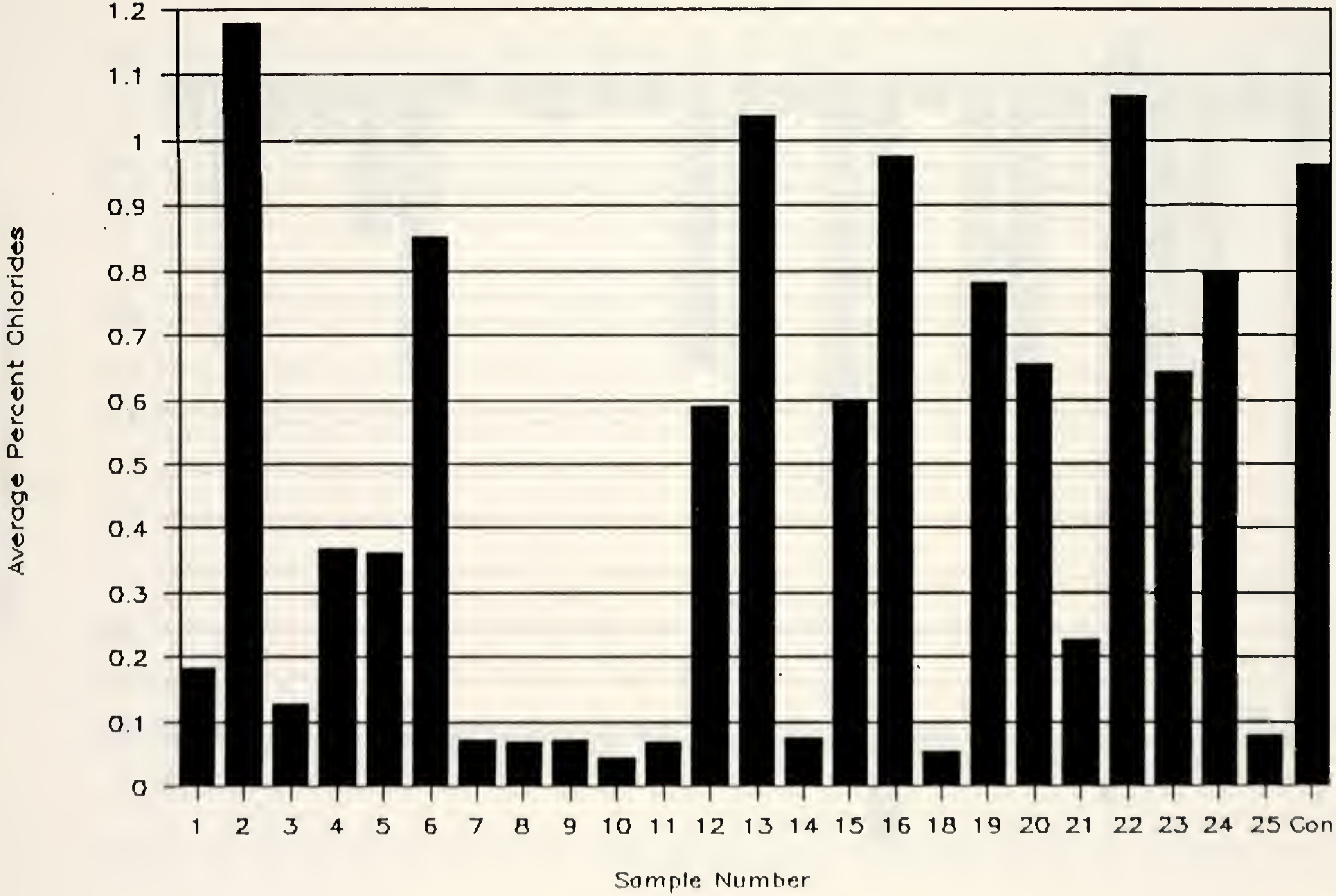

Figure D-2

Average Percent Chlorides at 0.50 in. Depth of Slab
Accelerated Weathering Titration

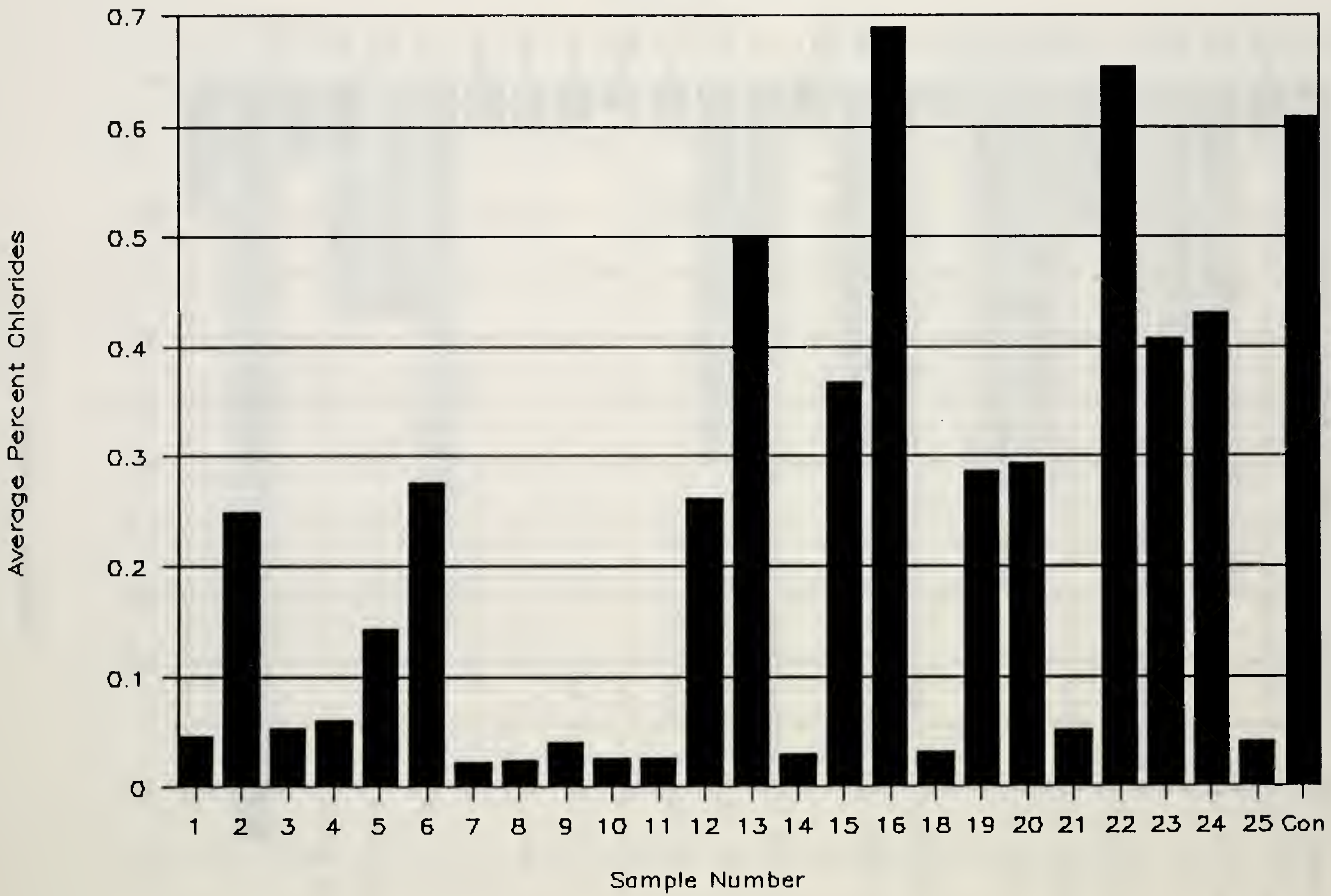

Figure D-3

Average Percent Chlorides at 1.00 in. Depth of Slab
Accelerated Weathering Titration

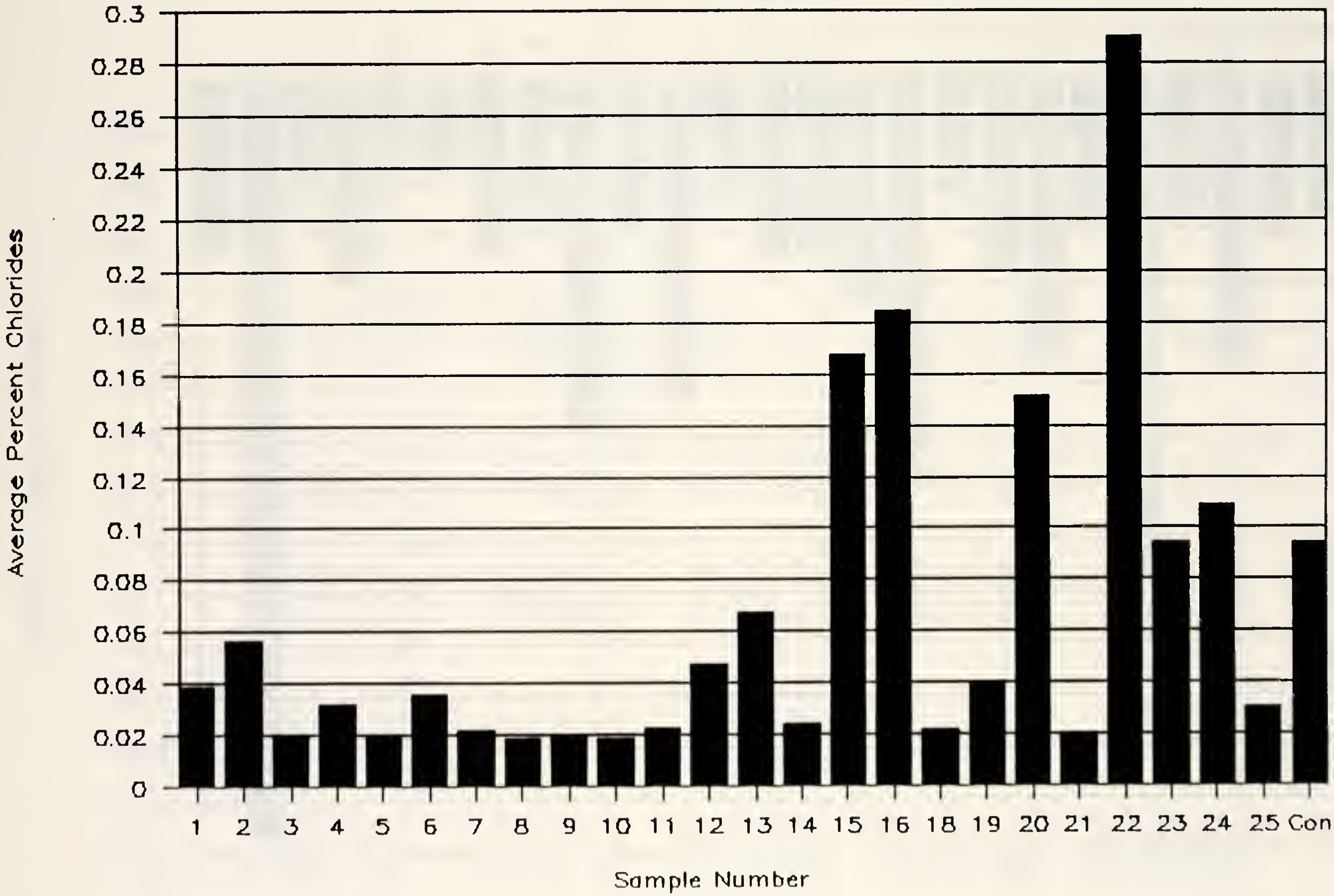

Figure D-4

Average Percent Chlorides at 1.50 in. Depth of Slab
Accelerated Weathering Titration

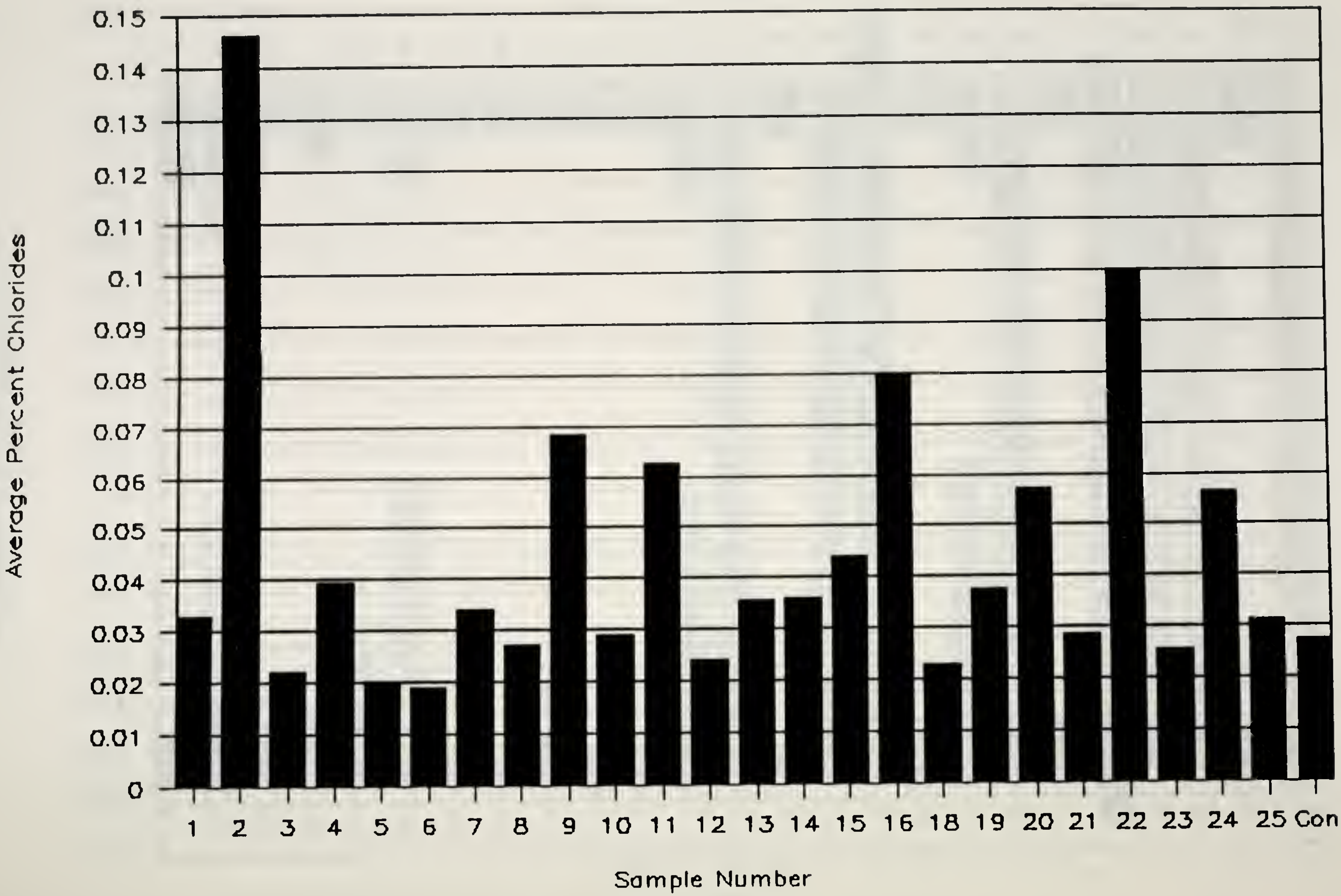

Figure D-5

Average Percent Chlorides at 2.00 in. Depth of Slab
Accelerated Weathering Titration

Table D-4

Individual Ponding Slab Titration Results

No. 1

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	6.72	7.62	7.170	0.171	0.194	0.1825
1.0	1.55	2.06	1.805	0.039	0.053	0.0460
1.5	2.33	0.68	1.505	0.060	0.017	0.0385
2.0	1.87	0.71	1.290	0.048	0.018	0.0330
						0.0750

No. 2

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	34.81	57.69	46.250	0.888	1.471	1.1795
1.0	14.20	5.24	9.720	0.362	0.134	0.2480
1.5	3.65	0.79	2.220	0.093	0.020	0.0565
2.0	1.90	9.52	5.710	0.049	0.243	0.1460
						0.4075

No. 3

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	6.89	3.11	5.000	0.176	0.079	0.1275
1.0	2.95	1.18	2.065	0.075	0.030	0.0525
1.5	0.91	0.61	0.762	0.023	0.016	0.0195
2.0	0.56	1.17	0.866	0.014	0.030	0.0220
						0.0554

No. 4

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	14.25	14.60	14.425	0.363	0.372	0.3675
1.0	2.13	2.55	2.340	0.054	0.065	0.0595
1.5	1.19	1.28	1.235	0.030	0.033	0.0315
2.0	2.06	1.00	1.530	0.053	0.026	0.0395
						0.1245

No. 5

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	13.89	14.59	14.240	0.354	0.372	0.3630
1.0	5.48	5.70	5.590	0.140	0.145	0.1425
1.5	0.72	0.84	0.780	0.018	0.021	0.0195
2.0	0.91	0.66	0.785	0.023	0.017	0.0200
						0.1363

Table D-4, continued

			No. 6			
Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	29.43	37.38	33.405	0.750	0.953	0.8515
1.0	6.73	14.83	10.780	0.172	0.378	0.2750
1.5	1.33	1.45	1.390	0.034	0.037	0.0355
2.0	0.78	0.72	0.752	0.020	0.018	0.0190
						0.2953

			No. 7			
Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	3.69	1.93	2.810	0.094	0.049	0.0715
1.0	1.12	0.70	0.910	0.028	0.018	0.0230
1.5	0.89	0.82	0.855	0.023	0.021	0.0220
2.0	1.63	1.01	1.320	0.042	0.026	0.0340
						0.0376

			No. 8			
Depth	lbs/cy	lbs/cy	Avg.	% chloride	% chloride	Average
0.5	2.66	2.84	2.750	0.068	0.072	0.0700
1.0	0.88	0.98	0.930	0.022	0.025	0.0235
1.5	0.59	0.89	0.740	0.015	0.023	0.0190
2.0	1.37	0.75	1.060	0.035	0.019	0.0270
						0.0349

			No. 9			
Depth	lbs/cy	lbs/cy	Avg.	% chloride	% chloride	Average
0.5	2.26	3.27	2.765	0.058	0.083	0.0705
1.0	0.91	2.23	1.570	0.023	0.057	0.0400
1.5	0.72	0.82	0.770	0.018	0.021	0.0195
2.0	2.14	3.21	2.675	0.055	0.082	0.0685
						0.0496

			No. 10			
Depth	lbs/cy	lbs/cy	Avg.	% chloride	% chloride	Average
0.5	1.68	1.76	1.720	0.043	0.045	0.0440
1.0	0.73	1.32	1.025	0.019	0.034	0.0265
1.5	0.65	0.78	0.715	0.017	0.020	0.0185
2.0	1.15	1.14	1.145	0.029	0.029	0.0290
						0.0295

Table D-4, continued

No. 11

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	2.19	3.08	2.635	0.056	0.079	0.0675
1.0	1.02	0.92	0.970	0.026	0.024	0.0250
1.5	0.94	0.84	0.890	0.024	0.021	0.0225
2.0	3.30	1.63	2.465	0.084	0.041	0.0625
						0.0444

No. 12

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	31.73	14.57	23.152	0.809	0.371	0.5900
1.0	14.95	5.51	10.230	0.381	0.141	0.2610
1.5	2.01	1.71	1.860	0.051	0.044	0.0475
2.0	0.70	1.15	0.925	0.019	0.029	0.0240
						0.2306

No. 13

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	38.24	43.07	40.655	0.975	1.098	1.0365
1.0	17.03	22.70	19.865	0.434	0.567	0.5005
1.5	2.65	2.60	2.625	0.068	0.066	0.0670
2.0	1.02	1.78	1.400	0.026	0.045	0.0355
						0.4099

No. 14

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	2.17	3.79	2.980	0.055	0.097	0.0760
1.0	0.87	1.49	1.180	0.022	0.038	0.0300
1.5	0.67	1.22	0.945	0.017	0.031	0.0240
2.0	1.20	1.62	1.410	0.031	0.041	0.0360
						0.0415

No. 15

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	5.04	41.87	23.455	0.128	1.068	0.5979
1.0	1.99	26.77	14.380	0.051	0.682	0.3665
1.5	0.75	12.40	6.575	0.019	0.316	0.1675
2.0	0.73	2.71	1.720	0.019	0.069	0.0440
						0.2940

Table D-4, continued

			No. 16			
Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	39.71	36.84	38.275	1.013	0.939	0.9758
1.0	24.69	29.39	27.040	0.630	0.749	0.6895
1.5	5.40	9.02	7.210	0.138	0.230	0.1840
2.0	4.97	1.27	3.120	0.127	0.032	0.0795
						0.4822
			No. 18			
Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	2.28	1.85	2.065	0.058	0.047	0.0525
1.0	1.19	1.23	1.210	0.030	0.031	0.0305
1.5	0.64	1.05	0.845	0.016	0.027	0.0215
2.0	1.00	0.82	0.910	0.025	0.021	0.0230
						0.0319
			No. 19			
Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	31.78	29.44	30.610	0.810	0.751	0.7805
1.0	9.52	12.94	11.230	0.243	0.330	0.2865
1.5	1.15	2.01	1.580	0.029	0.051	0.0400
2.0	1.14	1.82	1.480	0.029	0.046	0.0375
						0.2861
			No. 20			
Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	36.84	14.52	25.680	0.939	0.370	0.6545
1.0	21.07	1.98	11.525	0.538	0.051	0.2945
1.5	11.00	0.84	5.920	0.281	0.022	0.1515
2.0	3.28	1.17	2.225	0.084	0.030	0.0570
						0.2894
			No. 21			
Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	6.43	11.21	8.820	0.164	0.286	0.2250
1.0	1.45	2.59	2.020	0.037	0.066	0.0515
1.5	0.69	0.92	0.805	0.017	0.024	0.0205
2.0	0.90	1.34	1.120	0.023	0.034	0.0285
						0.0814

Table D-4, continued

No. 22

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	44.53	39.23	41.880	1.136	1.000	1.0680
1.0	27.39	23.82	25.605	0.700	0.608	0.6540
1.5	12.69	10.02	11.355	0.324	0.256	0.2900
2.0	5.21	2.44	3.825	0.133	0.067	0.1000
						0.5280

No. 23

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	21.84	28.56	25.200	0.557	0.728	0.6425
1.0	12.67	19.24	15.955	0.323	0.491	0.4070
1.5	2.71	4.68	3.695	0.069	0.119	0.0940
2.0	0.90	1.10	1.000	0.023	0.028	0.0255
						0.2923

No. 24

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	29.23	33.25	31.240	0.745	0.848	0.7965
1.0	17.31	16.41	16.860	0.441	0.419	0.4300
1.5	5.32	3.24	4.280	0.136	0.082	0.1090
2.0	2.72	1.73	2.225	0.069	0.044	0.0565
						0.3480

No. 25

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	3.29	2.86	3.075	0.084	0.073	0.0785
1.0	1.62	1.51	1.565	0.041	0.038	0.0395
1.5	1.07	1.29	1.180	0.027	0.033	0.0300
2.0	1.18	1.28	1.230	0.030	0.033	0.0315
						0.0449

Control

Depth	lbs/cy	lbs/cy	Average	% chloride	% chloride	Average
0.5	37.00	38.38	37.690	0.944	0.979	0.9615
1.0	22.80	24.87	23.835	0.582	0.634	0.6080
1.5	4.07	3.33	3.700	0.104	0.085	0.0945
2.0	0.98	1.16	1.070	0.025	0.030	0.0275
						0.4229

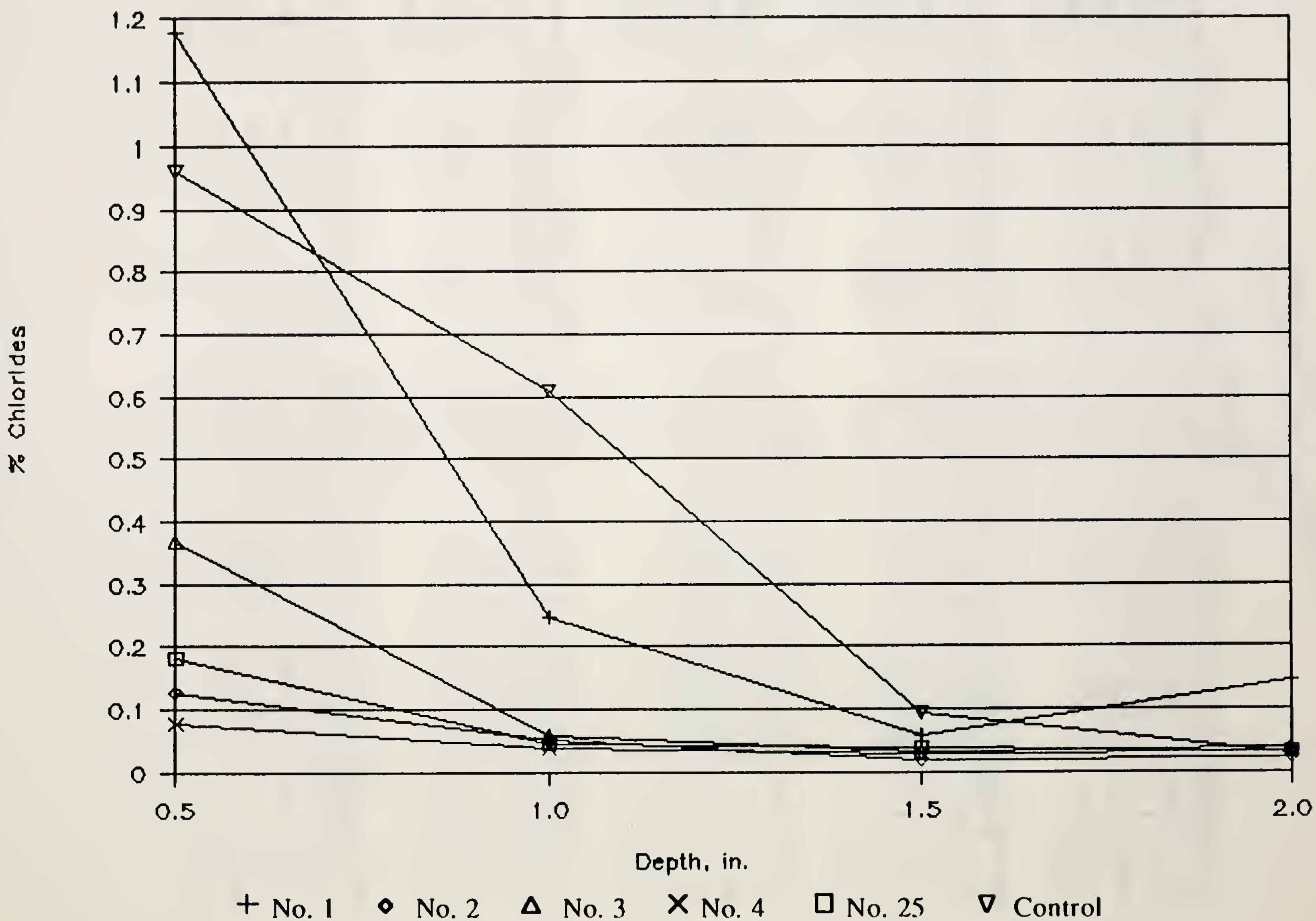

Figure D-6

Accelerated Weathering Chloride Titration Results - Epoxies

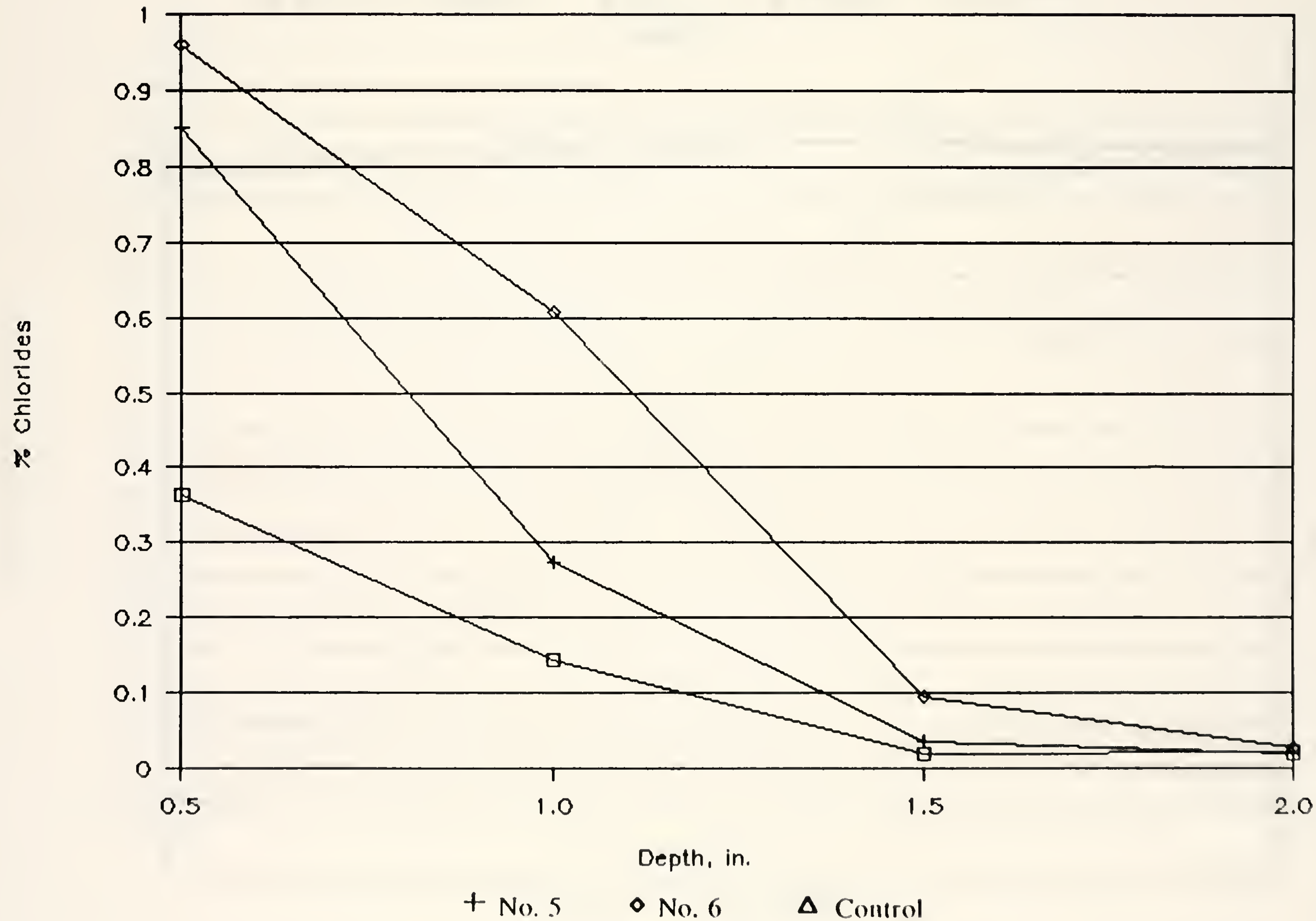

Figure D-7

Accelerated Weathering Chloride Titration Results - Urethanes

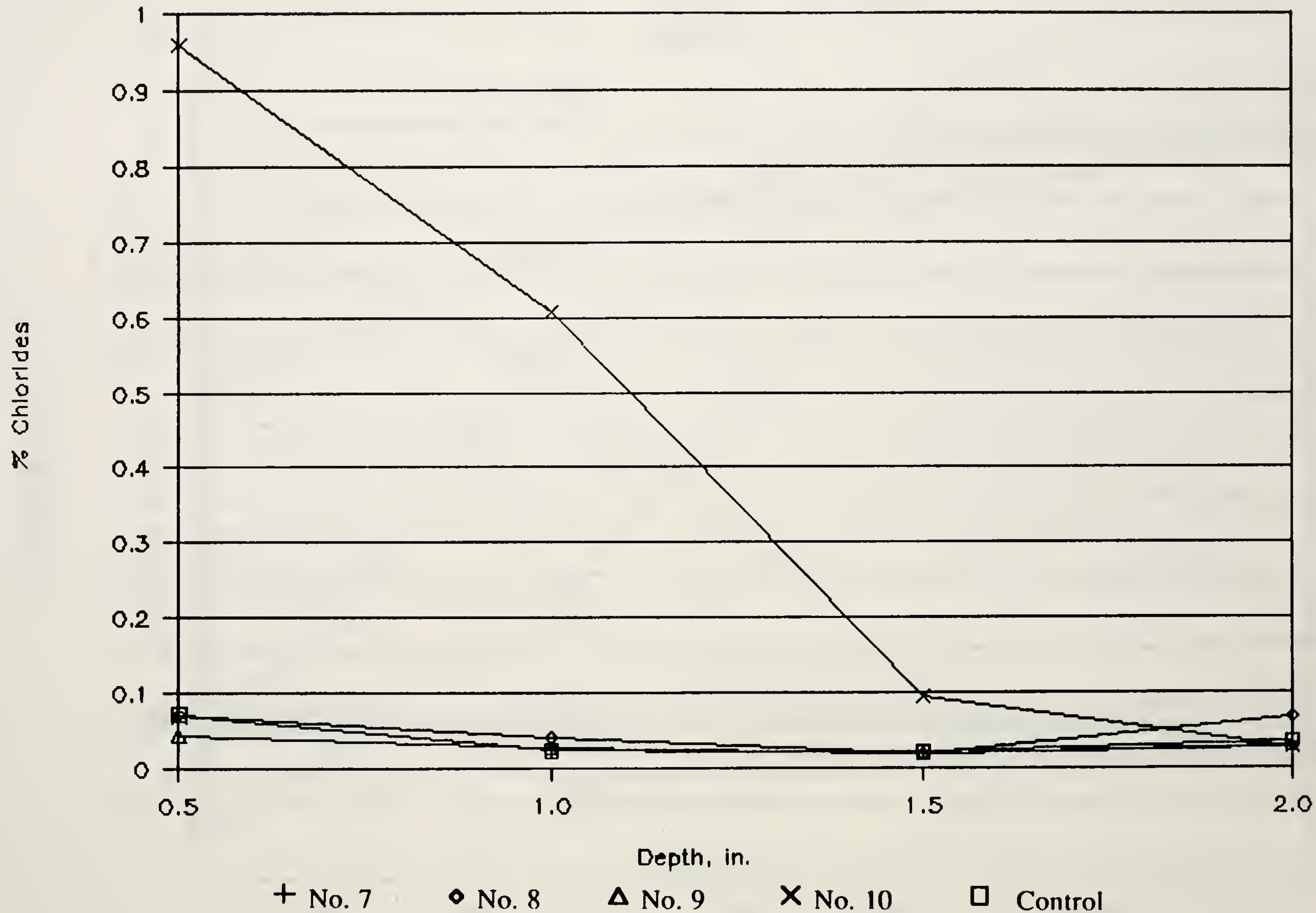

Figure D-8

Accelerated Weathering Chloride Titration Results - Silanes

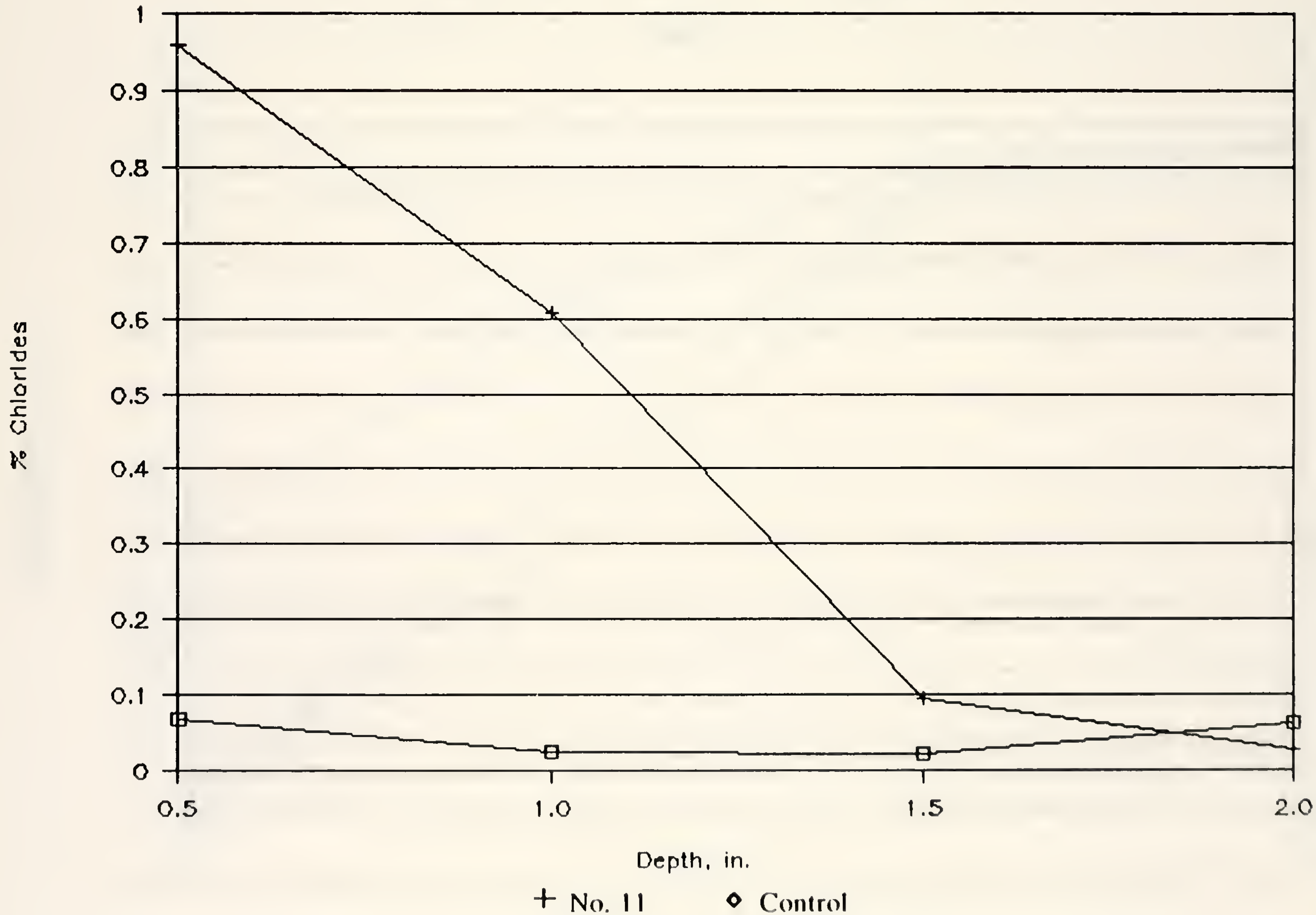

Figure D-9

Accelerated Weathering Chloride Titration Results - Silicone

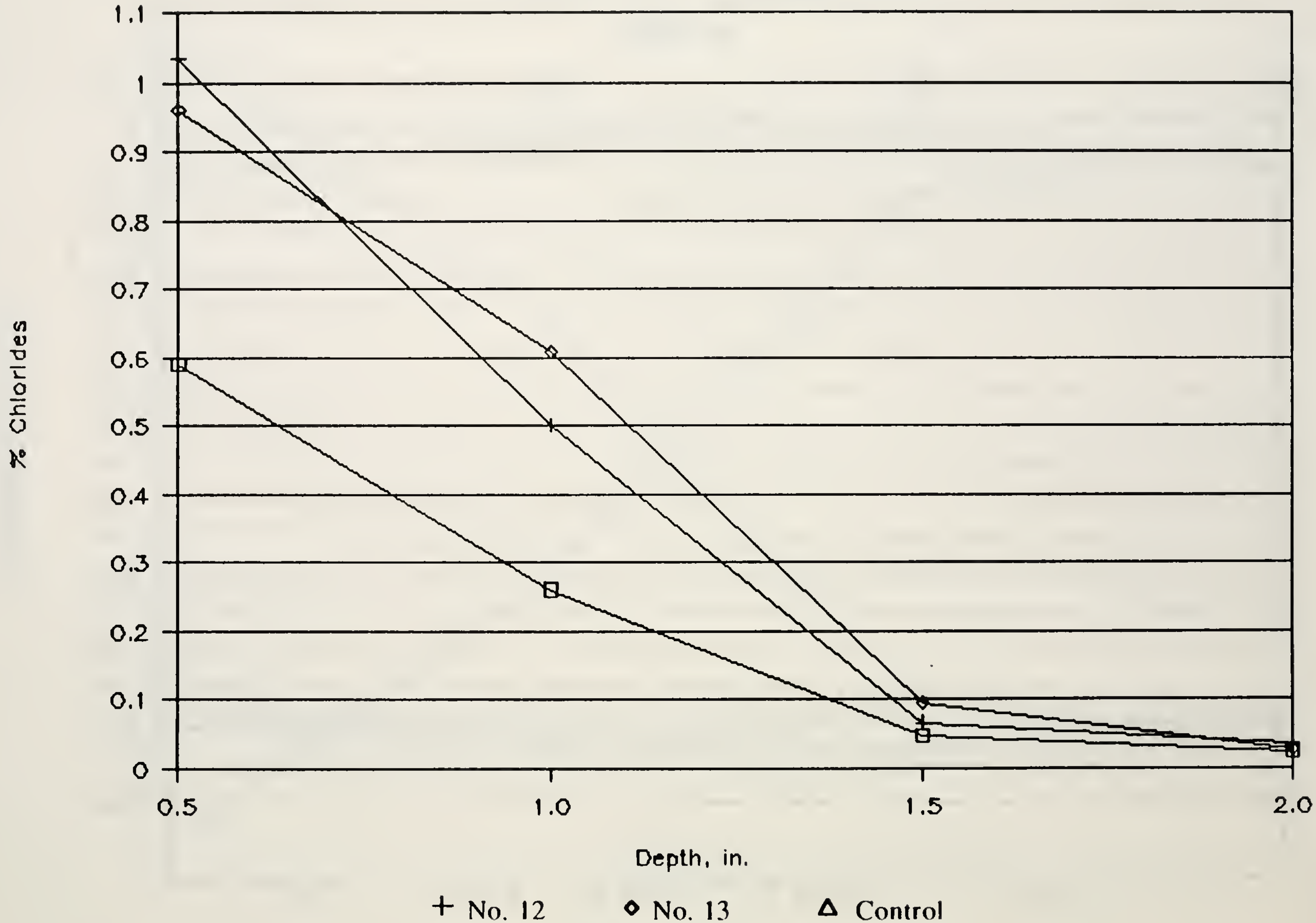

Figure D-10

Accelerated Weathering Chloride Titration Results - Methyl Methacrylates

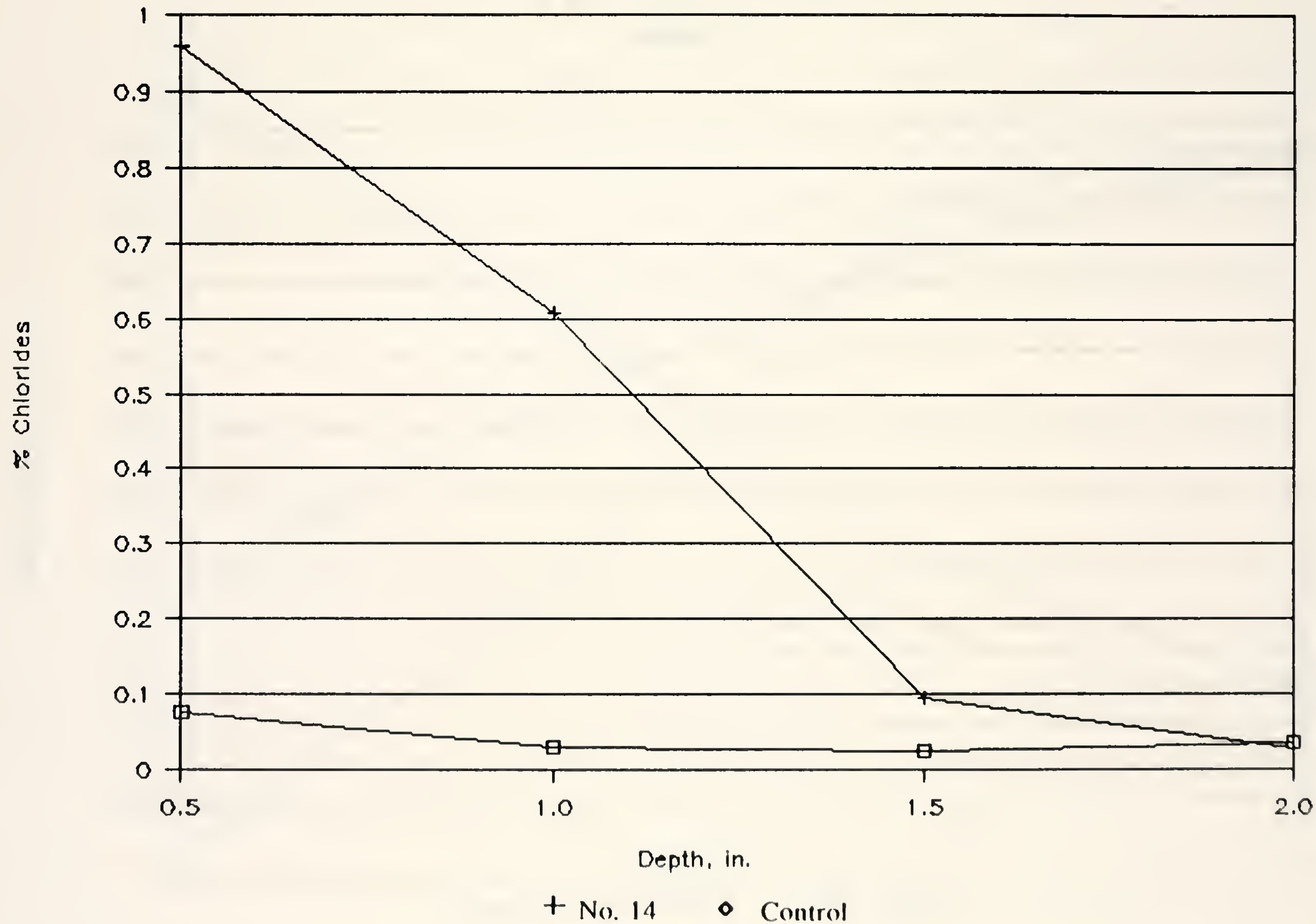

Figure D-11

Accelerated Weathering Chloride Titration Results - Siloxane

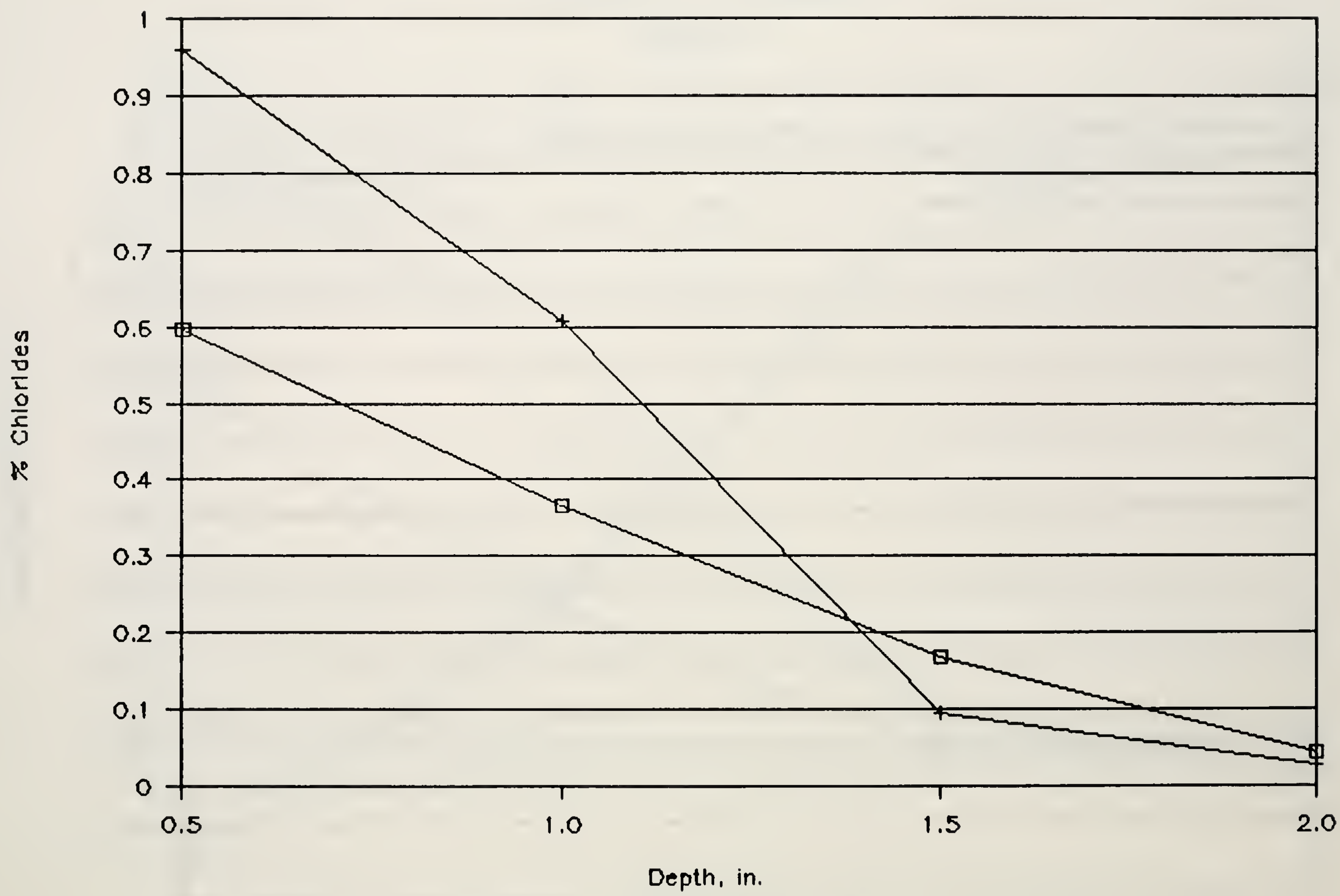

Figure D-12

Accelerated Weathering Chloride Titration Results - Siloxane/Silicone

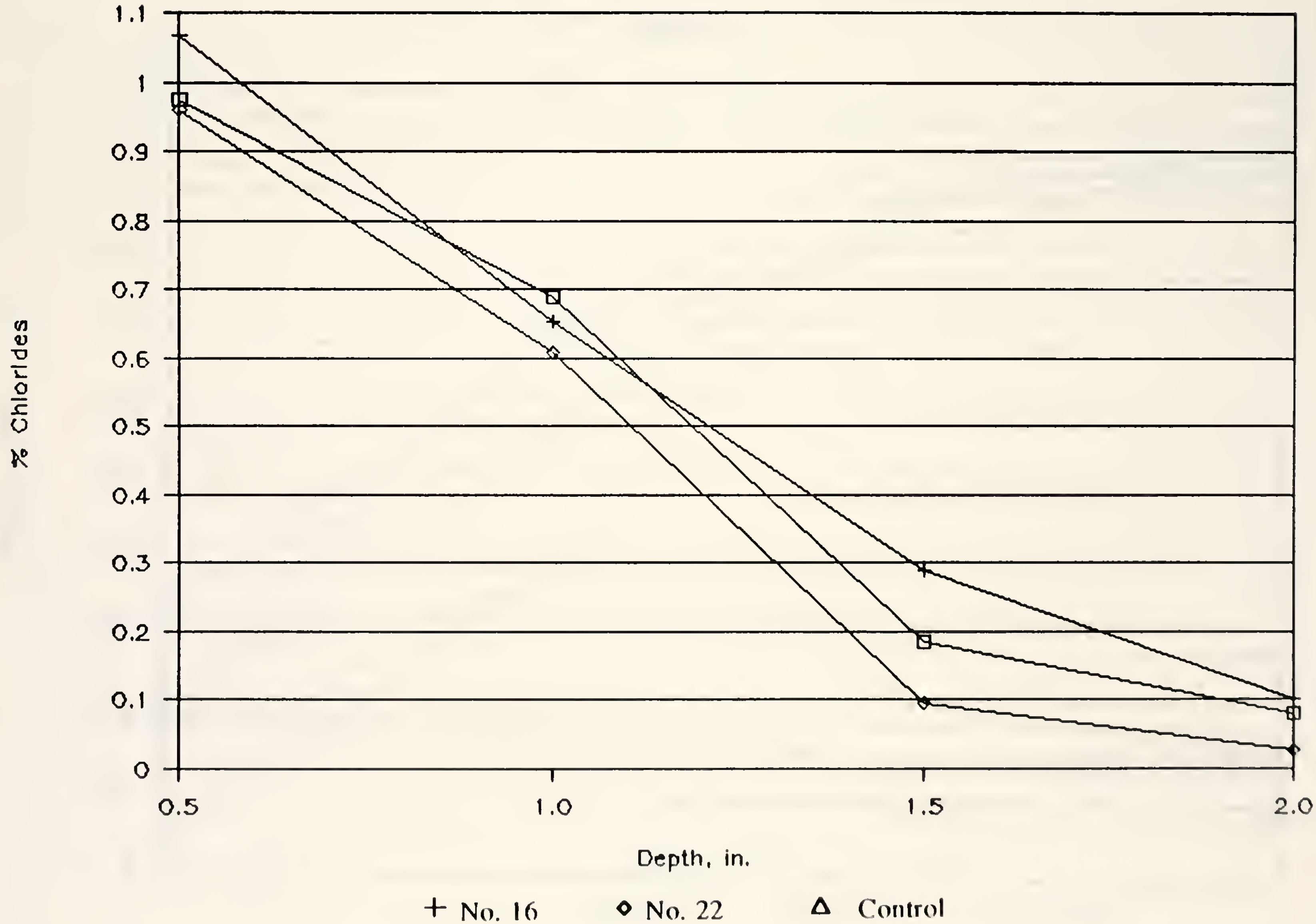

Figure D-13

Accelerated Weathering Chloride Titration Results - Styrene Acrylic Copolymers

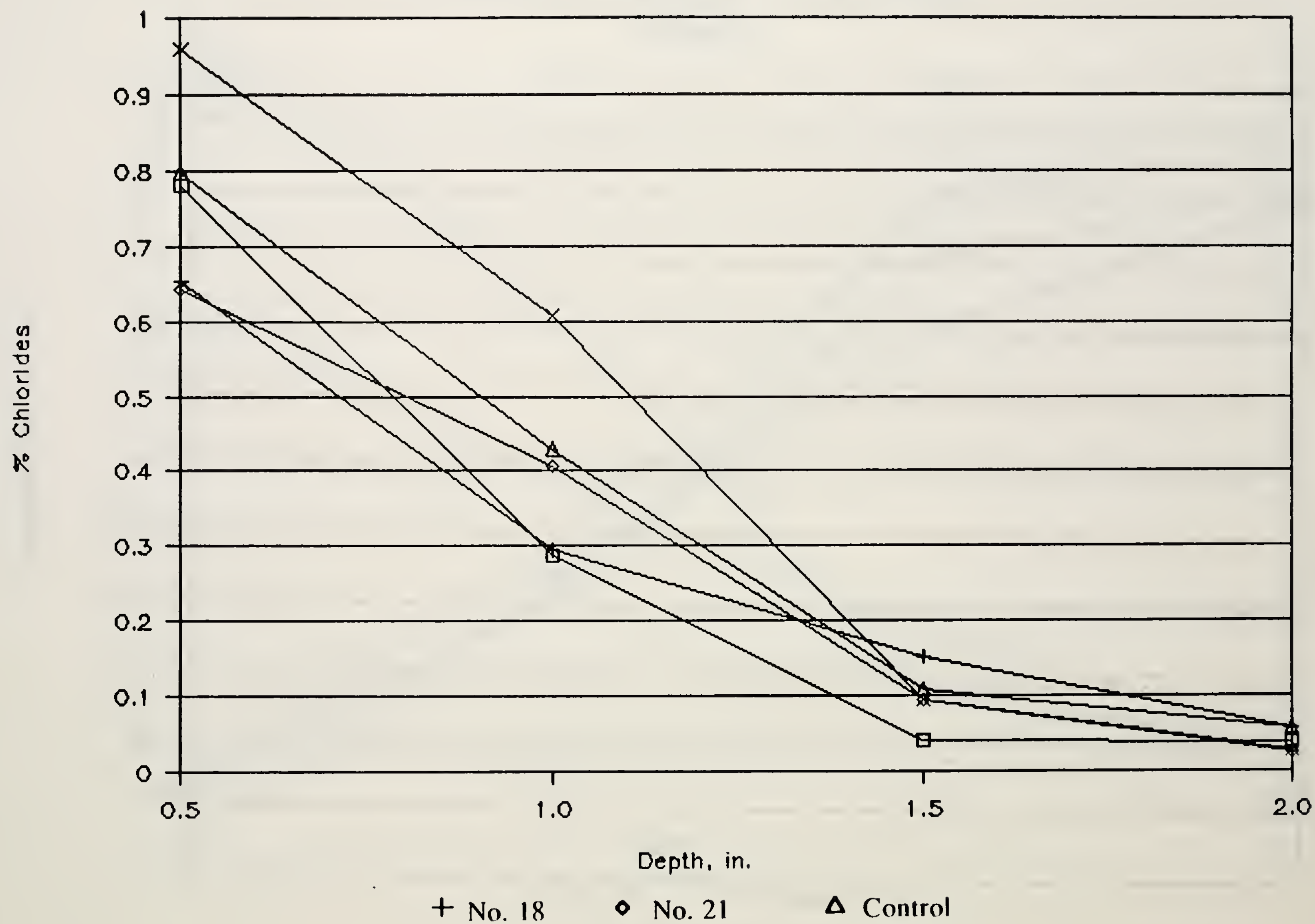

Figure D-14

Accelerated Weathering Chloride Titration Results - Silane Combinations

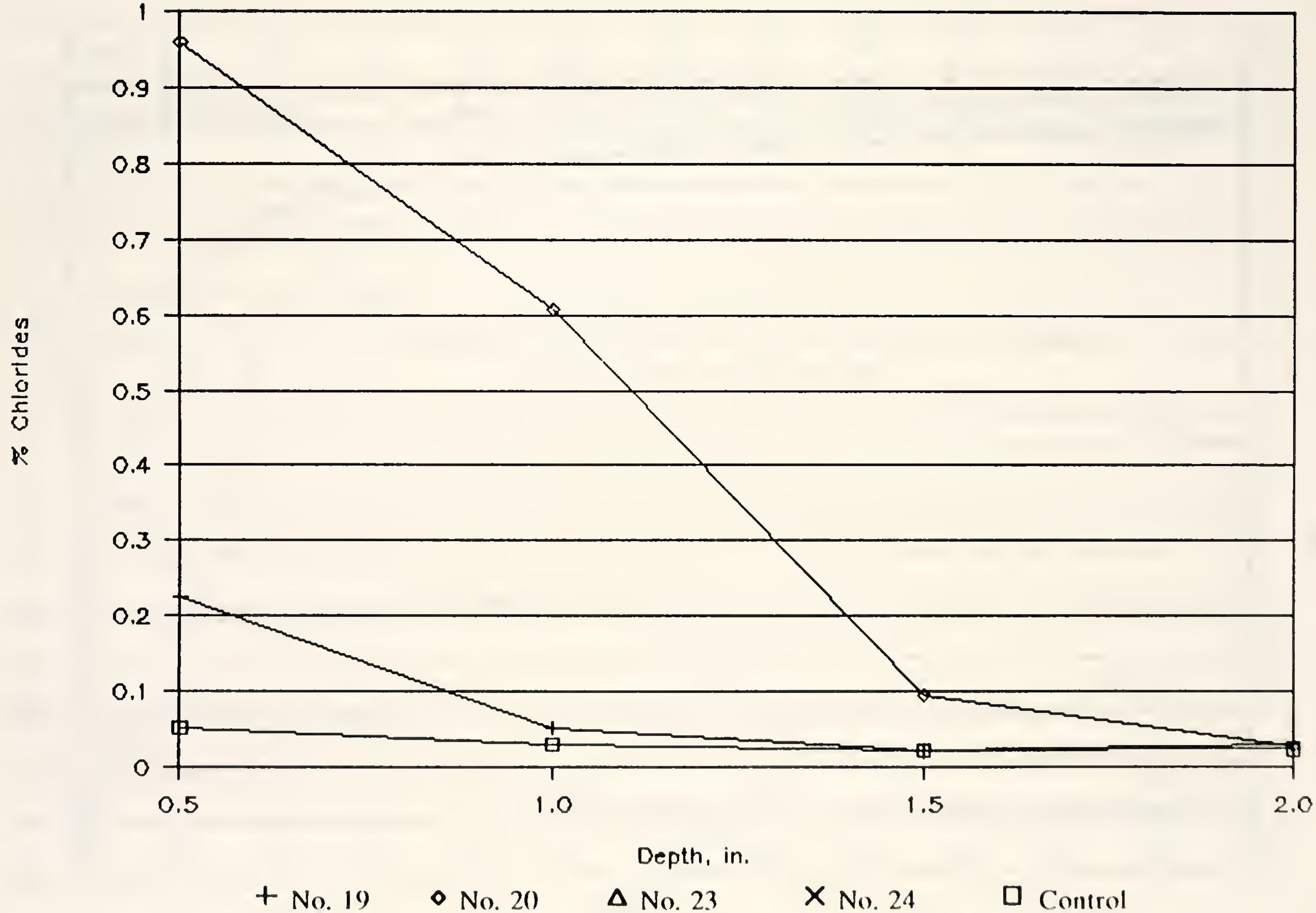

Figure D-15

Accelerated Weathering Chloride Titration Results - Masonry Coatings

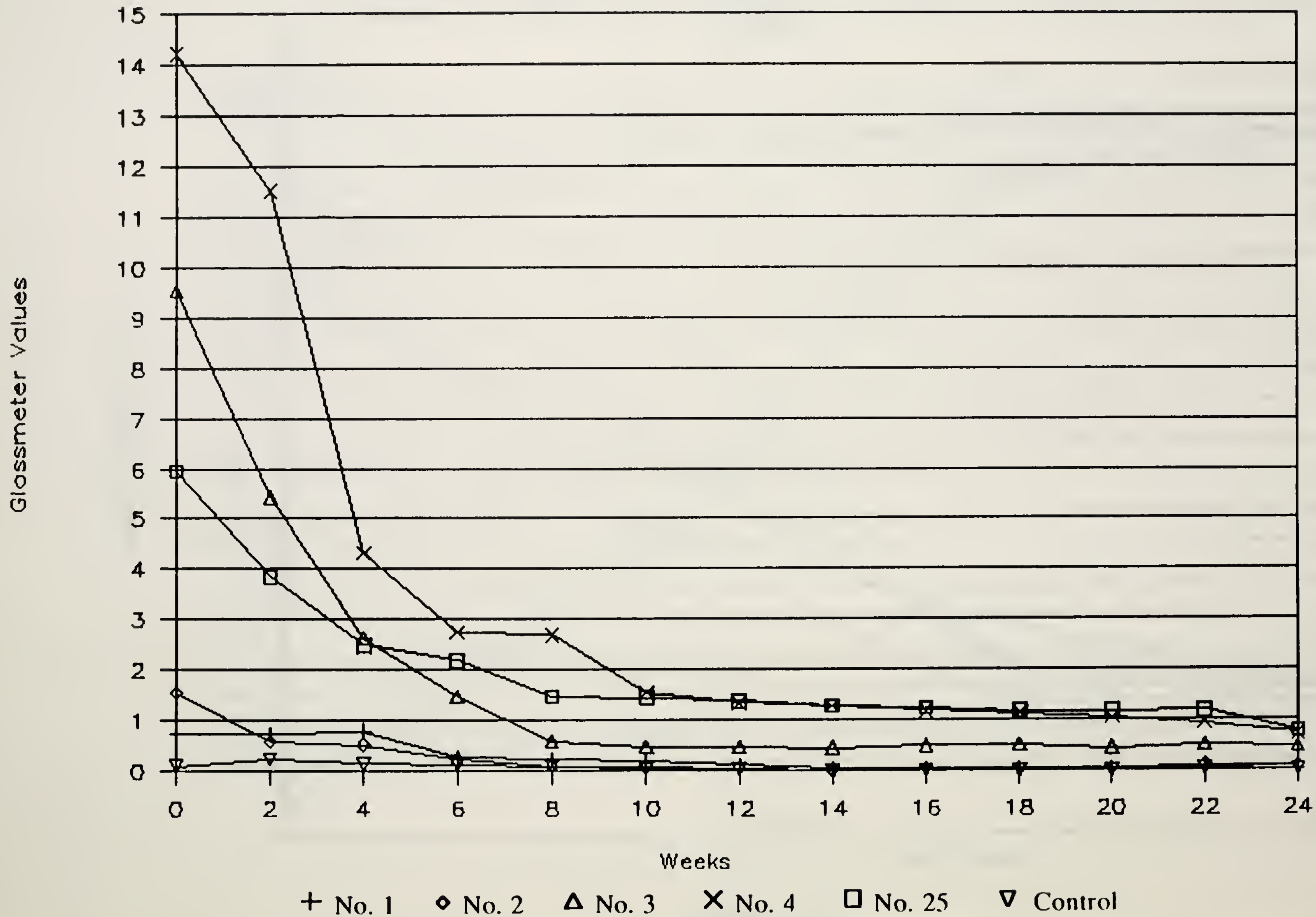

Figure D-16

Accelerated Weathering Glossmeter Results

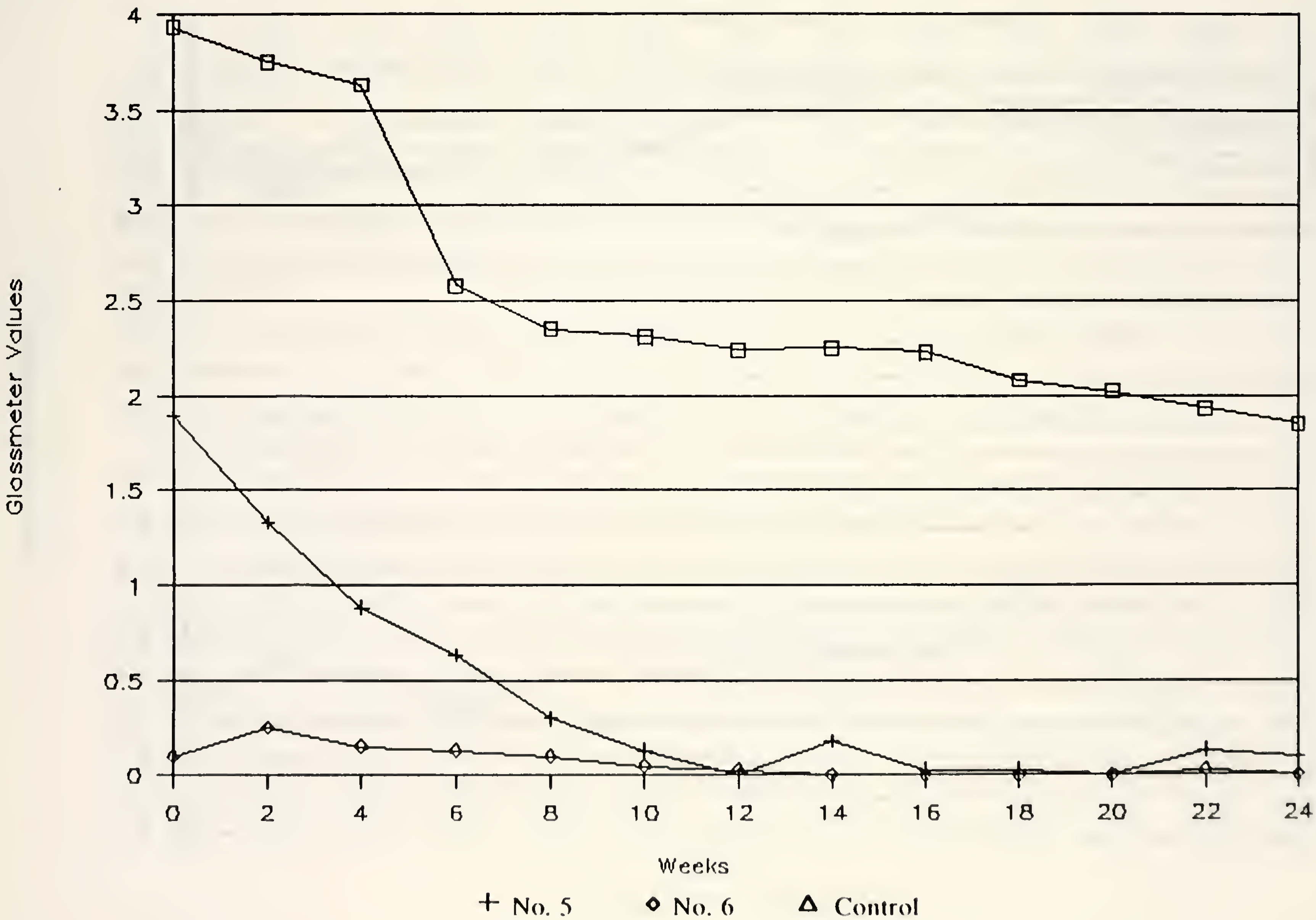

Figure D-17

Accelerated Weathering Glossmeter Results - Urethanes

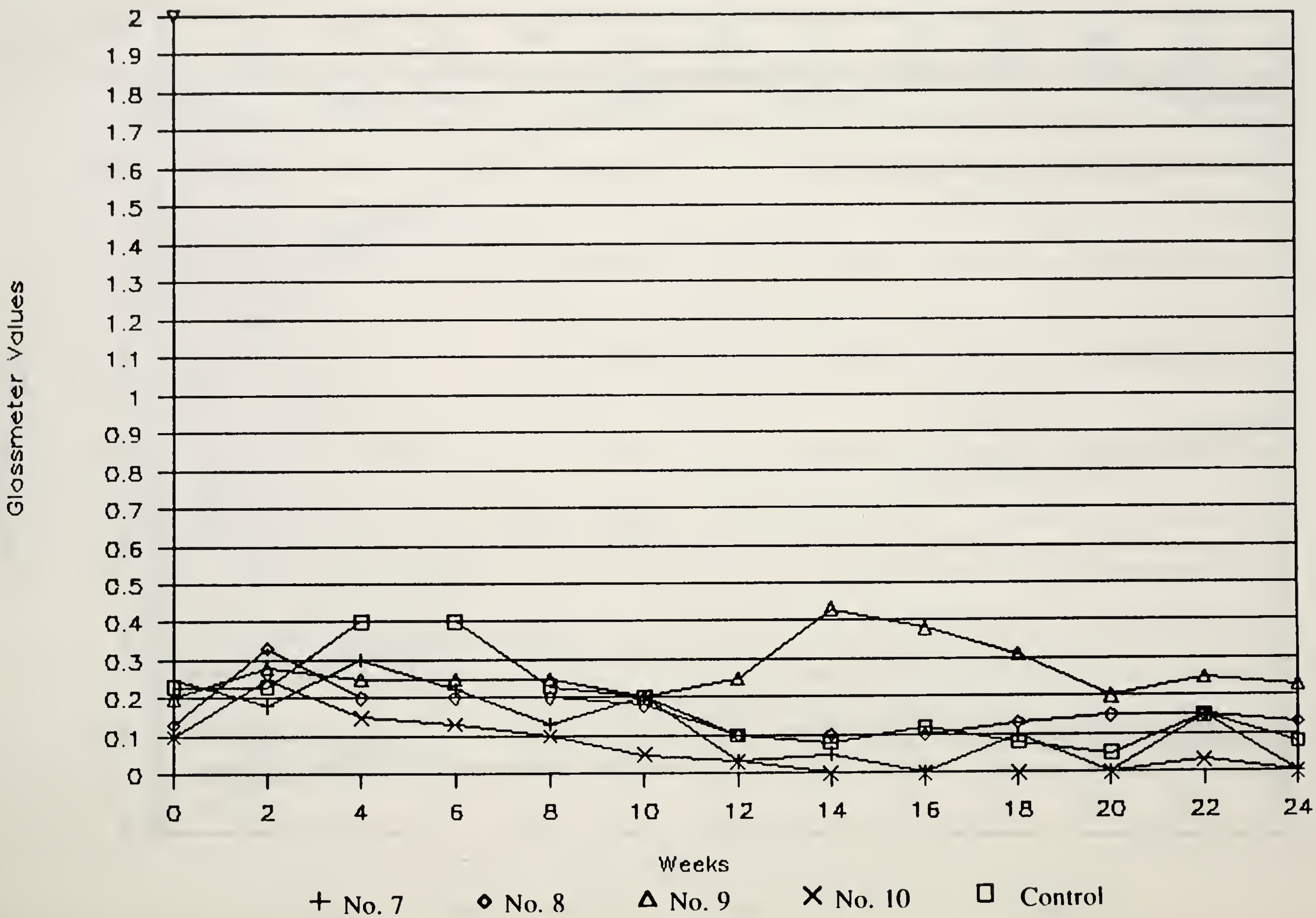

Figure D-18

Accelerated Weathering Glossmeter Results - Silanes

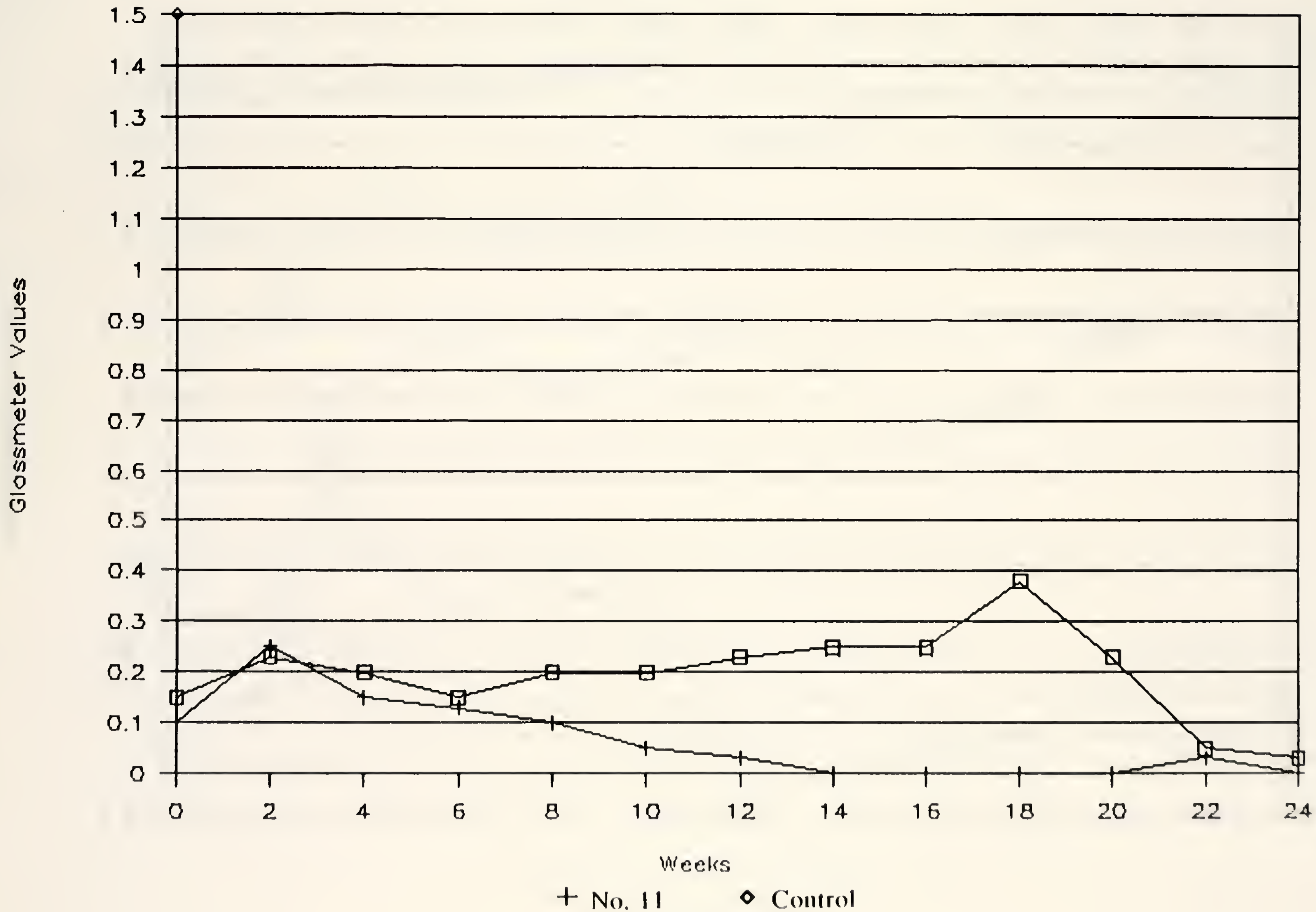

Figure D-19

Accelerated Weathering Glossmeter Results - Silicone

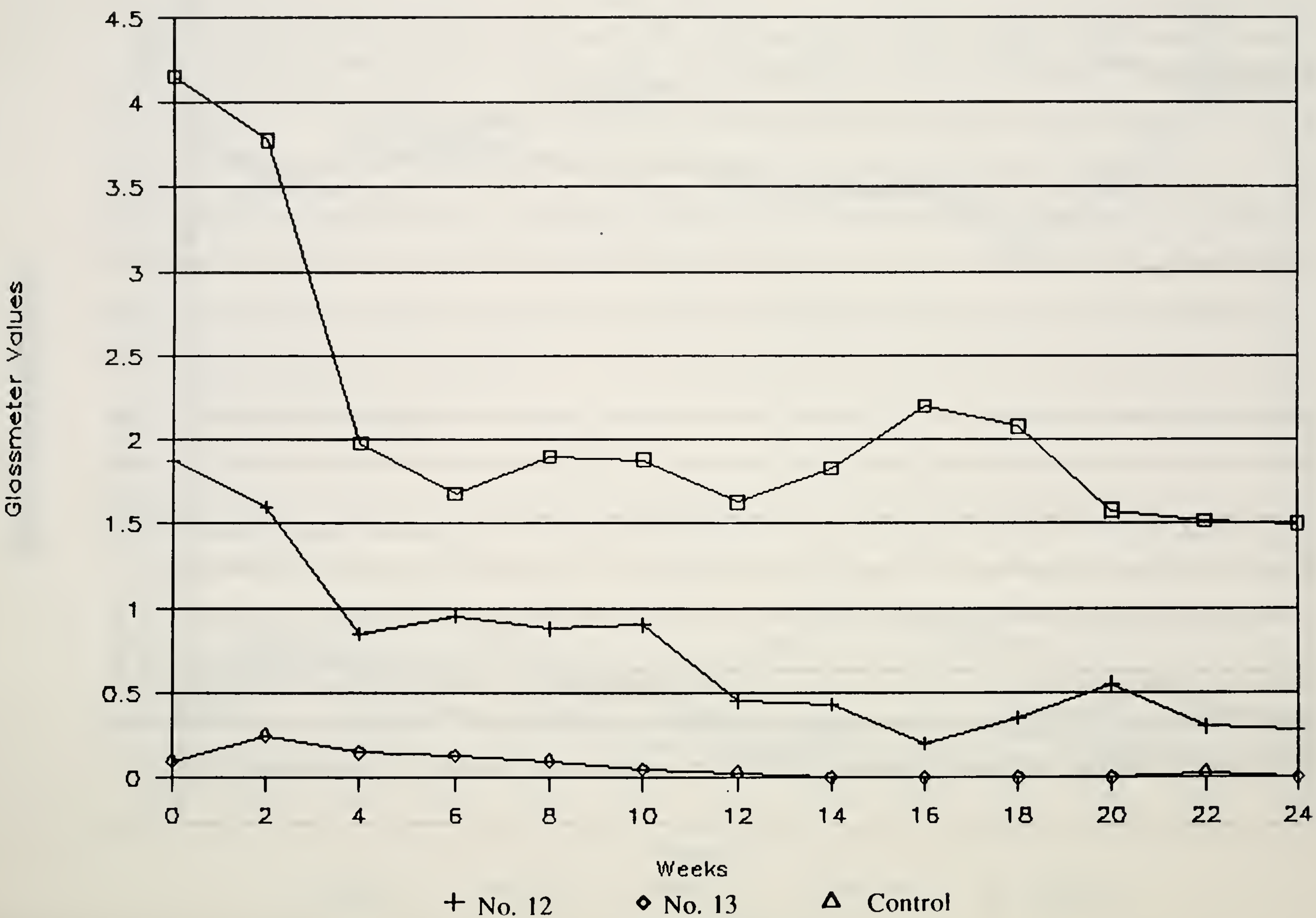

Figure D-20

Accelerated Weathering Glossmeter Results - Methyl Methacrylates

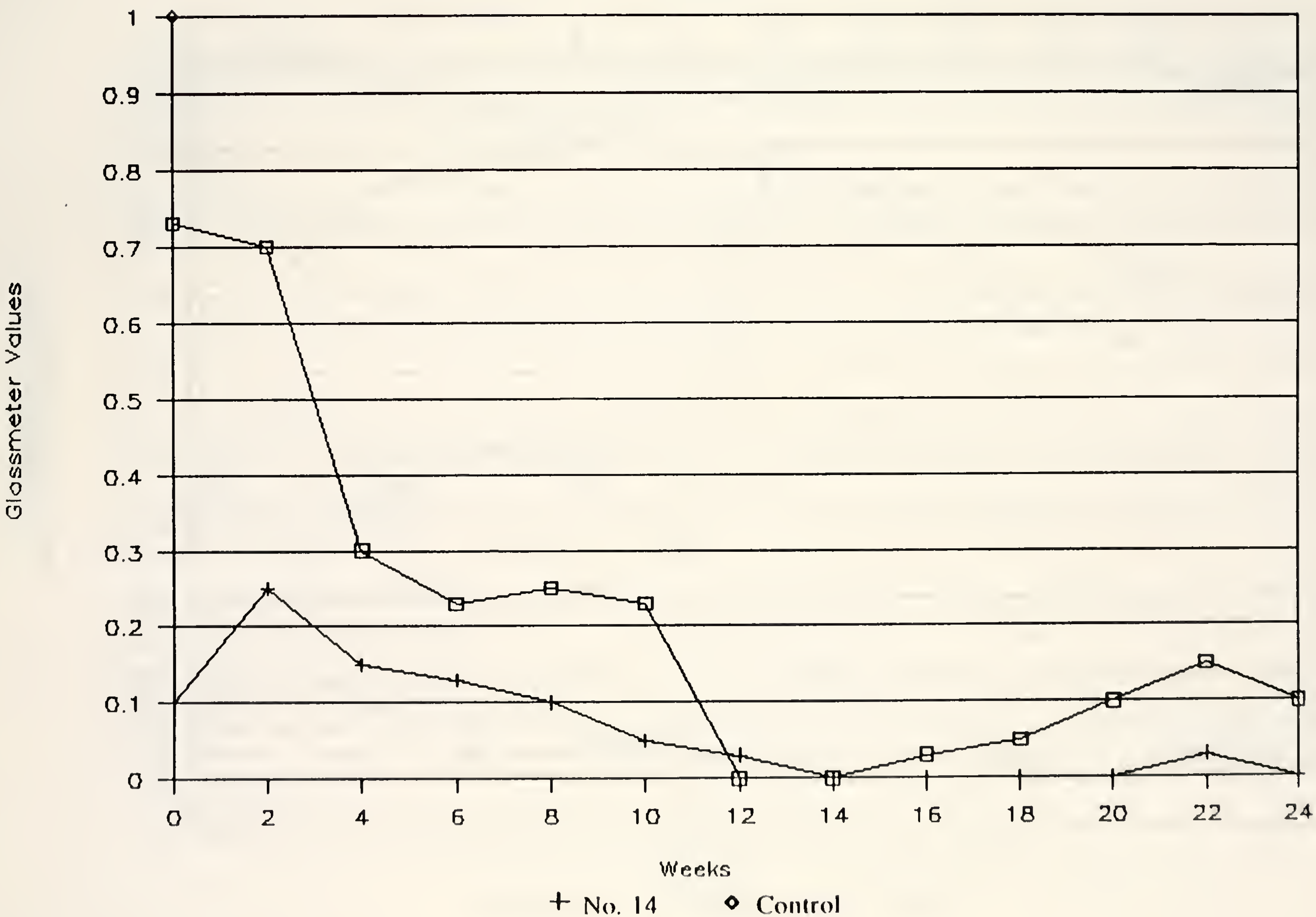

Figure D-21

Accelerated Weathering Glossmeter Results - Siloxane

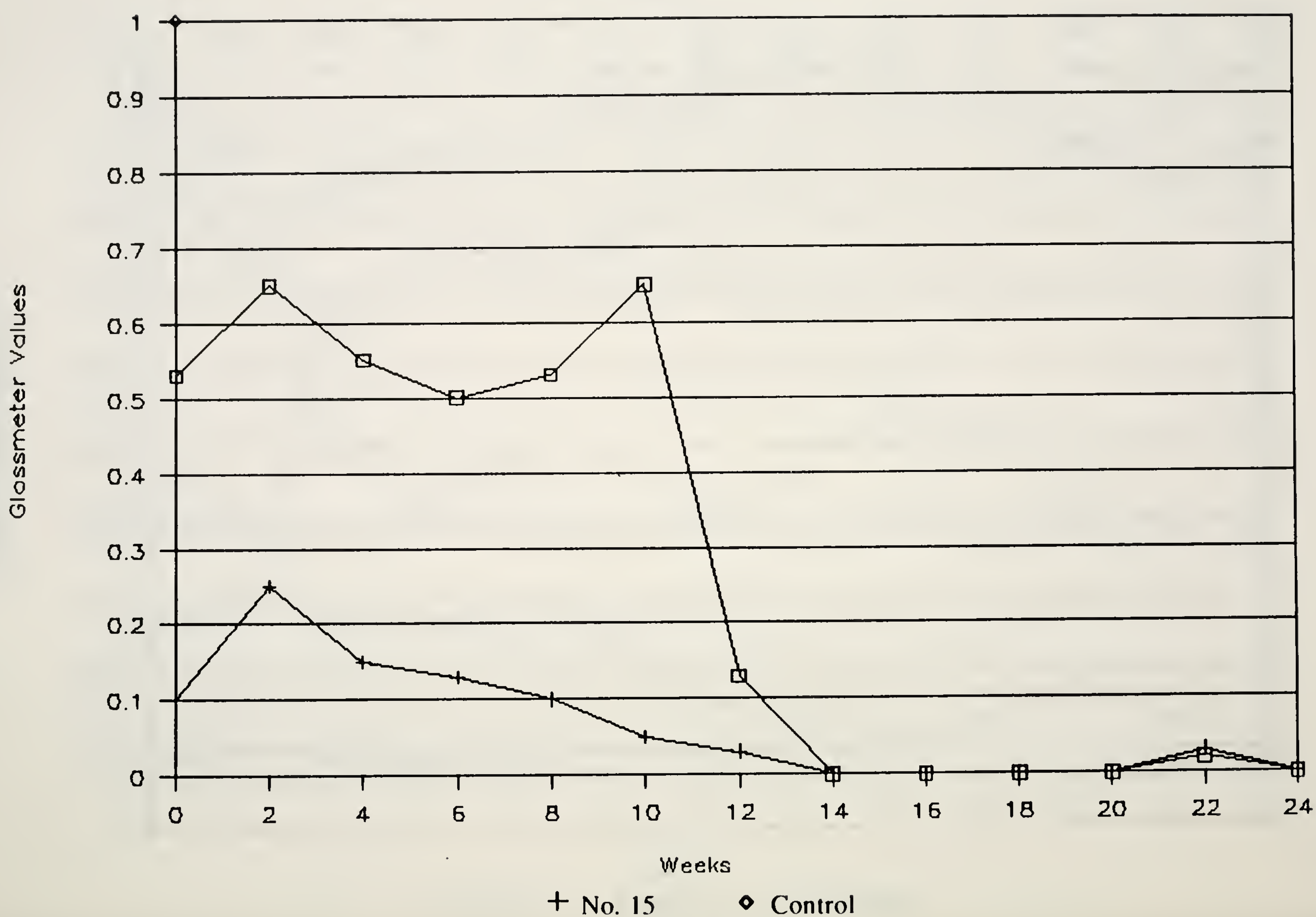

Figure D-22

Accelerated Weathering Glossmeter Results - Siloxane/Silicone

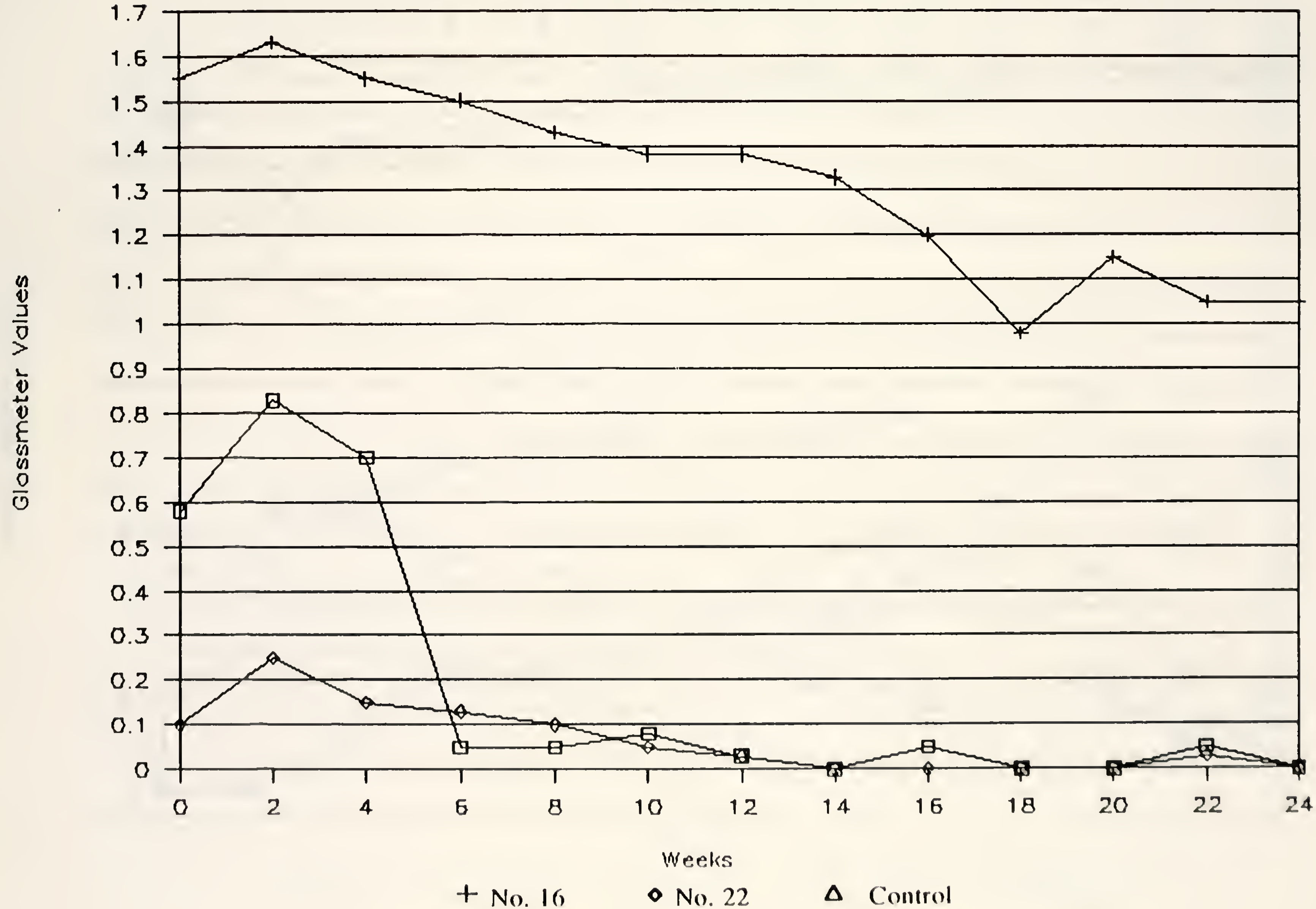

Figure D-23
Accelerated Weathering Glossmeter Results - Styrene Acrylic Copolymers

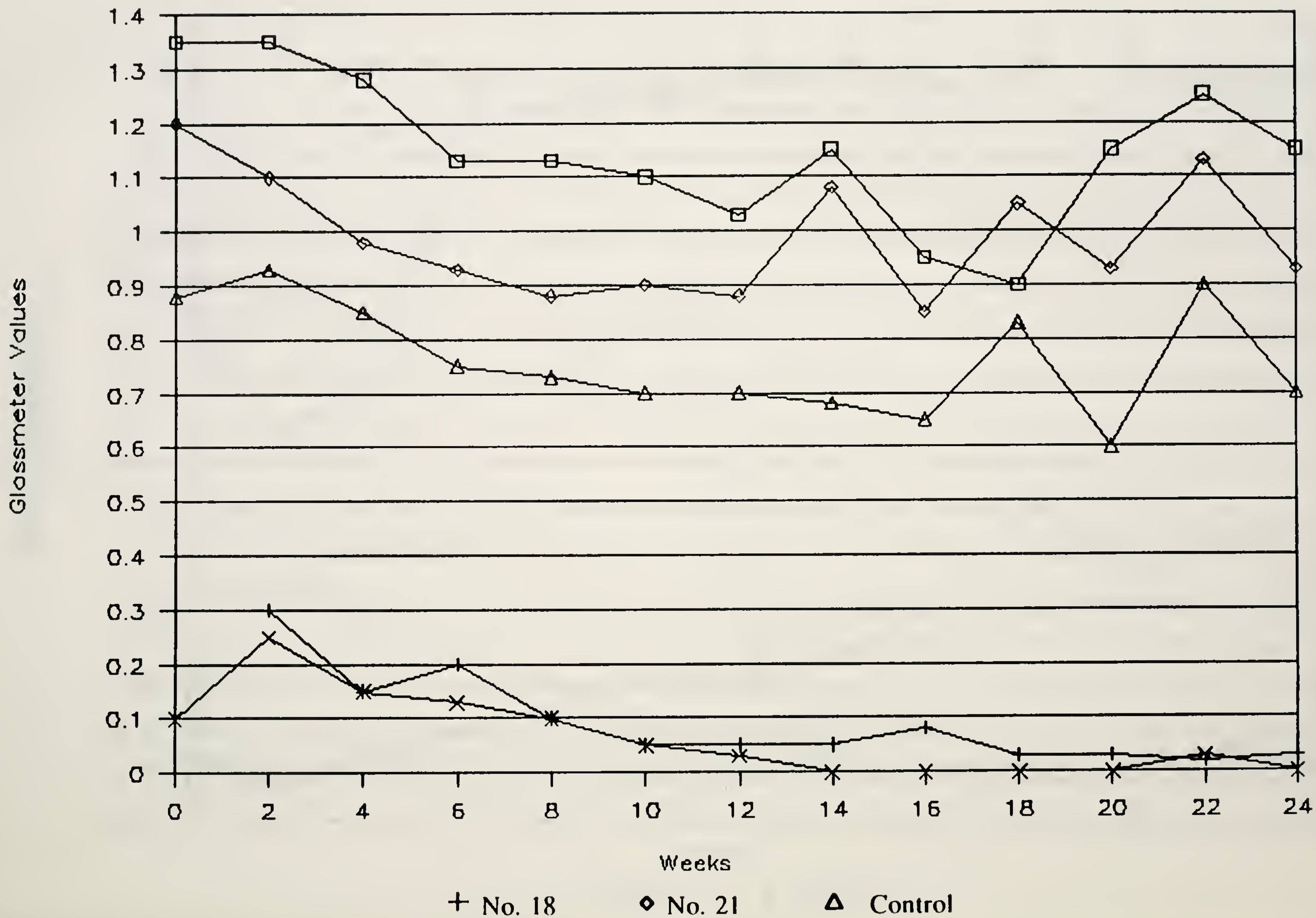

Figure D-24

Accelerated Weathering Glossmeter Results - Silane

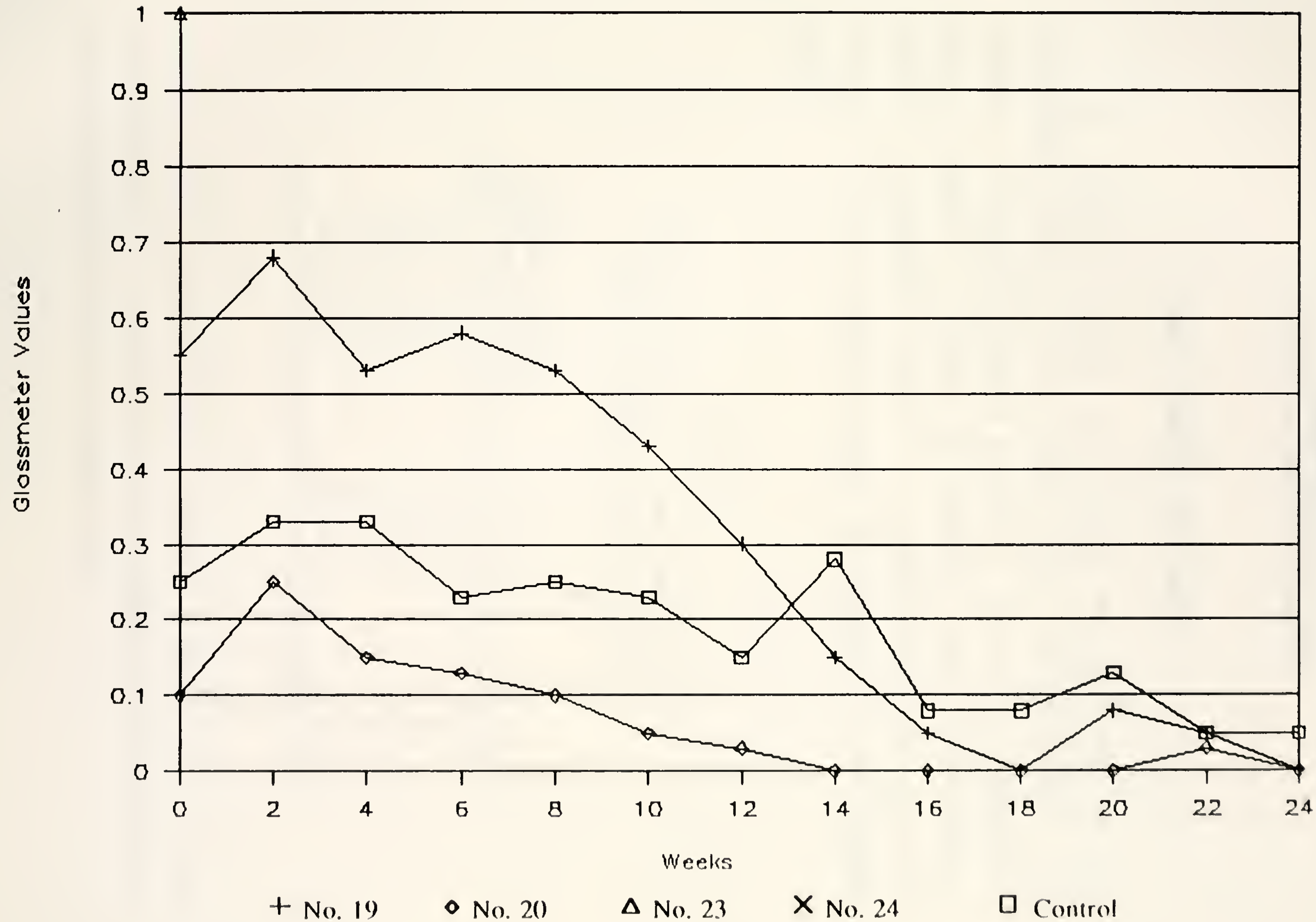

Figure D-25

Accelerated Weathering Glossmeter Results - Masonry Coatings

Appendix E
Statistical Analysis of Data

Rapid Chloride Permeability

A statistical analysis was run on the data from the five penetrating epoxies that were coated at three different periods. The analysis was greatly hampered because of the lack of repetition of the test cylinders. The results did, however, indicate a few points, as shown in the following, Table E-1. A Newman-Keuls test was run on the data and the computer ranked the samples in the following order:

Table E-1

Statistical Analysis - Penetrating Epoxies
Rapid Chloride Permeability Test

Sample Number and Percent Solids	Means	Rank
No. 3 - 50	685.0	1
No. 4 - 50	722.7	2
No. 1 - 50	995.3	3
No. 26 - 50	1058.7	4
No. 2 - 20	1726.7	5

Another result of this statistical analysis was that the top four epoxies (Nos. 3, 4, 1, and 26) were not significantly different with a 95 % and even with a 90 % confidence level.

Water Absorption/Vapor Transmission

A statistical analysis was run on the data from the water absorption and vapor transmission phases of this test. Table E-2 displays the computer ranking of the samples for the soaking phase, normal laboratory environment drying phase (73 degrees F and 50% RH), and the super drying phase (100 degrees F and 27% RH) according to the Newman-Keuls statistical analysis test.

Another conclusion from this statistical analysis was that there was no significant difference between the different coating periods (Set 1 - 9 days, Set 2 - 19 days, and Set 3 - 28 days) with reference to all of the samples during the soaking period. There was, however, a significant difference between the coating periods for the normal drying phase. As would be expected, the samples in Set 3, as a whole, lost more weight than the other two sets. Set 3 was followed by Set 2 and finally by Set 1. During the super drying phase, the samples in Set 1, as a whole, lost more weight than the other two sets. These results were calculated with a 95% confidence level.

As mentioned above, the extent of statistical analysis was greatly limited because of the lack of repetition of the samples. However, the results that were obtained from the statistical analysis tests run on the Rapid Chloride Permeability and Water Abs./Vapor Trans. test data did reinforce the conclusions that had been previously made according to engineering judgement.

Table E-2
Statistical Analysis - Water Abs./ Vapor Trans.

Rank	Soaking (21 Days) Sample No.	Phase I - Drying Normal (24 Days) Sample No.	Phase II- Drying Super (12 Days) Sample No.
1	12 - Methyl M.	25 - Epoxy	25 - Epoxy
2	4 - Epoxy	5 - Urethane	5 - Urethane
3	1 - Epoxy	4 - Epoxy	1 - Epoxy
4	25 - Epoxy	1 - Epoxy	4 - Epoxy
5	10 - Silane	8 - Silane	3 - Epoxy
6	14 - Siloxane	10 - Silane	19 - Masonry Coat.
7	11 - Silicone	11 - Silicone	2 - Epoxy
8	8 - Silane	15 - Silox./Silicone	10 - Silane
9	7 - Silane	14 - Siloxane	23 - Masonry Coat.
10	5 - Urethane	2 - Epoxy	18 - Blend of Sil.
11	2 - Epoxy	7 - Silane	16 - Masonry Coat.
12	15 - Silox./Silicone	12 - Methyl M.	24 - Masonry Coat.
13	9 - Silane	18 - Blend of Sil.	13 - Methyl M.
14	3 - Epoxy	9 - Silane	14 - Siloxane
15	18 - Blend of Sil.	16 - Masonry Coat.	15 - Silox./Silicone
16	13 - Methyl M.	3 - Epoxy	9 - Silane
17	20 - Masonry Coat.	13 - Methyl M.	6 - Urethane
18	22 - Masonry Coat.	20 - Masonry Coat.	11 - Silicone
19	16 - Masonry Coat.	22 - Masonry Coat.	7 - Silane
20	6 - Urethane	23 - Masonry Coat.	12 - Methyl M.
21	23 - Masonry Coat.	24 - Masonry Coat.	20 - Masonry Coat.
22	24 - Masonry Coat.	19 - Masonry Coat.	21 - Silane Mix
23	19 - Masonry Coat.	6 - Urethane	22 - Masonry Coat.
24	21 - Silane Mix	21 - Silane Mix	8 - Silane

COVER DESIGN BY ALDO GIORGINI